Ice Sheets, Sea Ice and Satellites
Transforming Polar Paradigms

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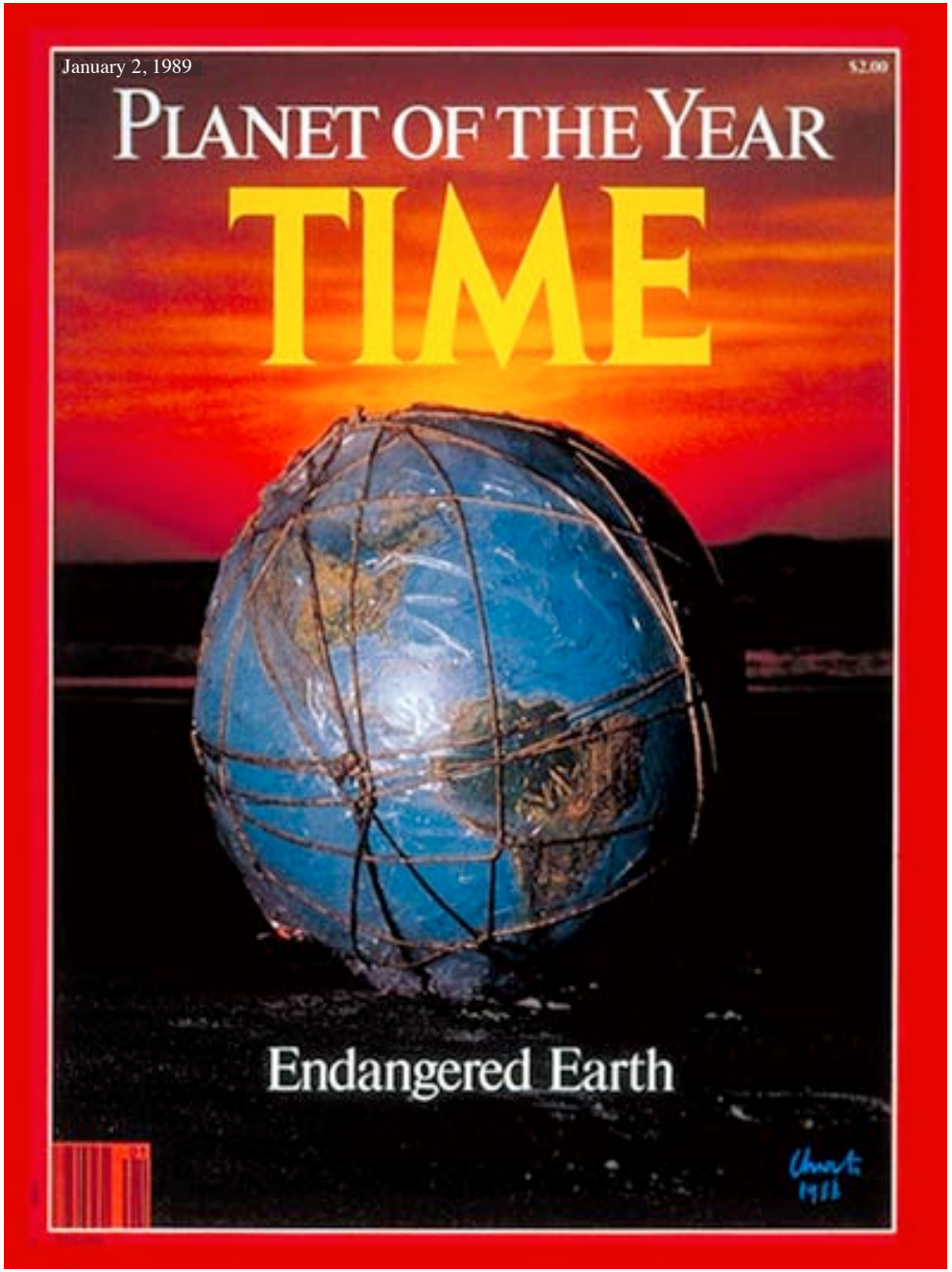
University of Colorado, Boulder, CO

Acknowledgements

- The Cryospheric Science Community
- Colleagues at NASA HQ
- NASA Public Affairs and the Scientific Visualization Studio
- Everyone who had the wisdom, foresight perseverance to make the Earth Observing System a reality
- Everyone who is working to enable the next generation Earth Observing Program



"The pictures provide clear evidence that the earth is in grave danger as a result of human activity."

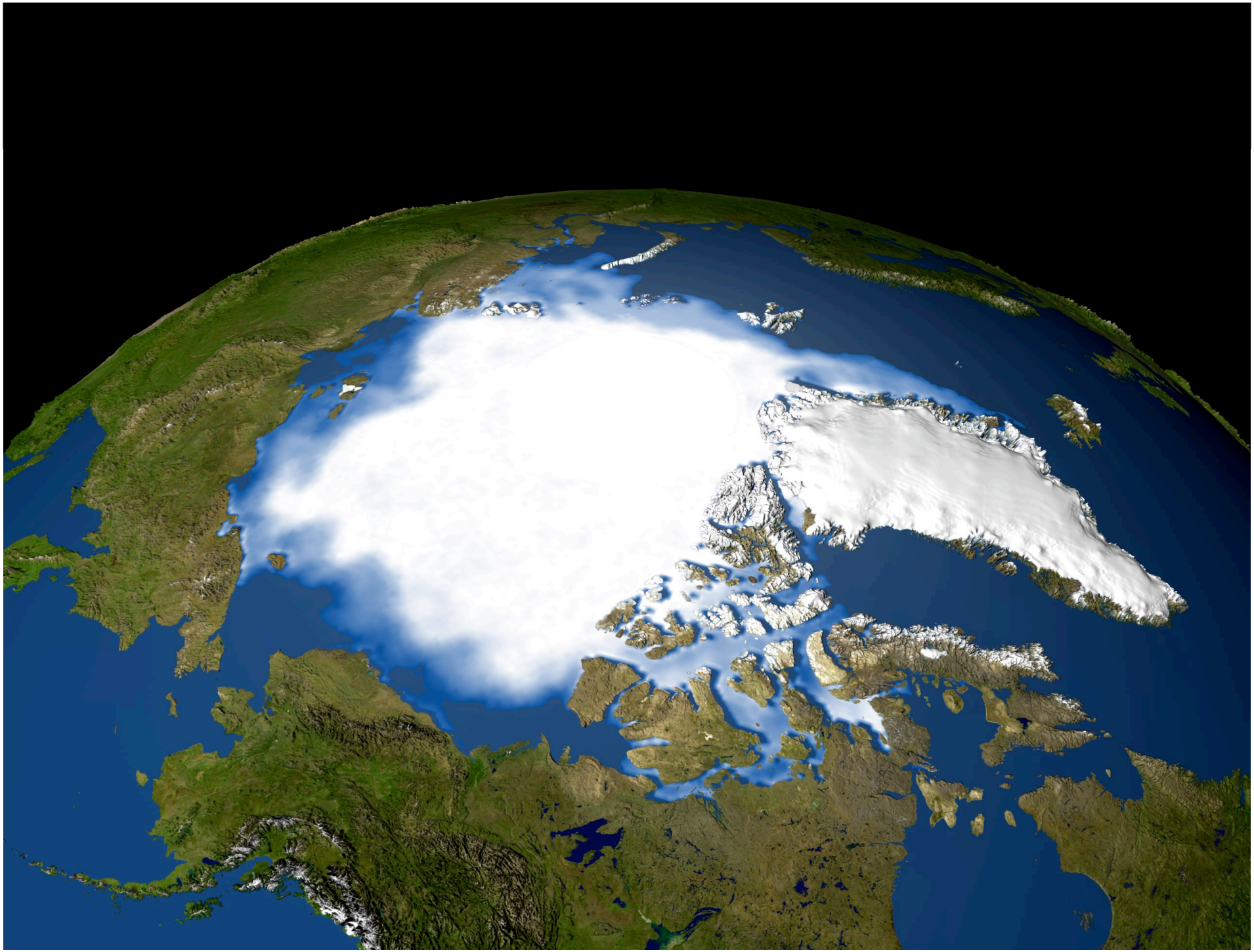
"Major help in studying the earth's environment is expected to emerge from a project being planned by the National Aeronautics and Space Administration. Called Mission to Planet Earth... "

"Mission to Planet Earth would go a long way toward answering critics who have insisted that the U.S. space program has for years had no clear mission."

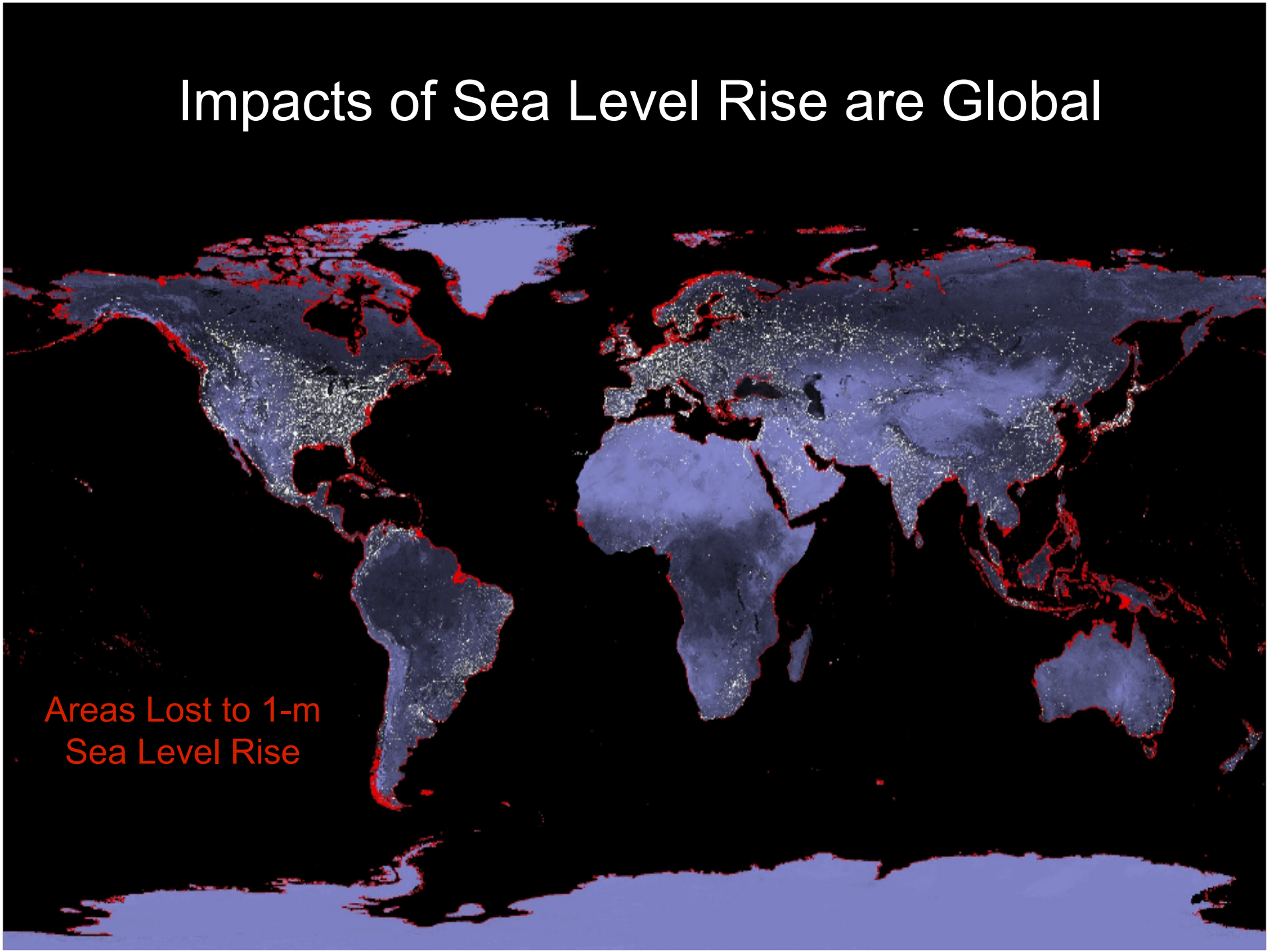
Time Magazine,
June 5, 1989

“Man must rise above the Earth - to the top of the atmosphere and beyond - for only thus will he fully understand the world in which he lives.”

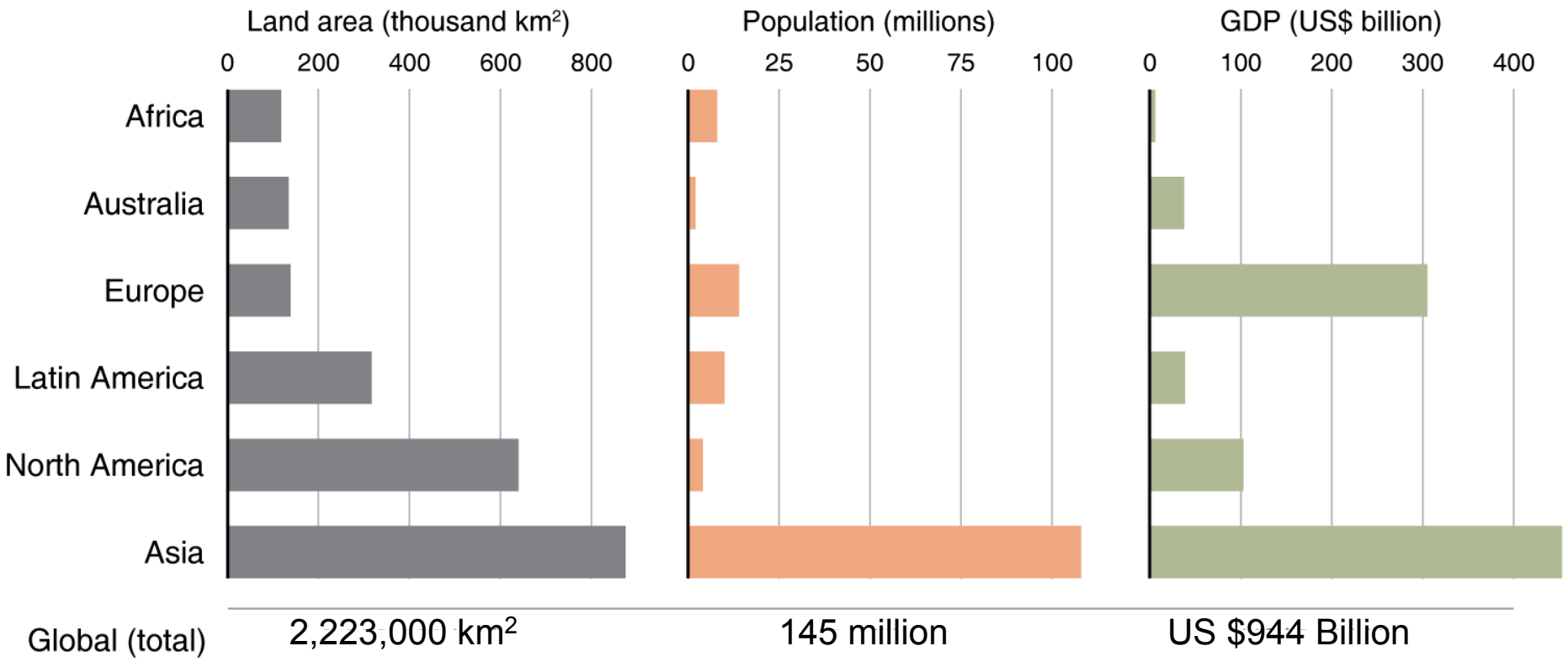
Socrates, ca 400 BC



Impacts of Sea Level Rise are Global



What is at Risk with a 1-meter Sea Level Rise



From Anthoff et al., 2006

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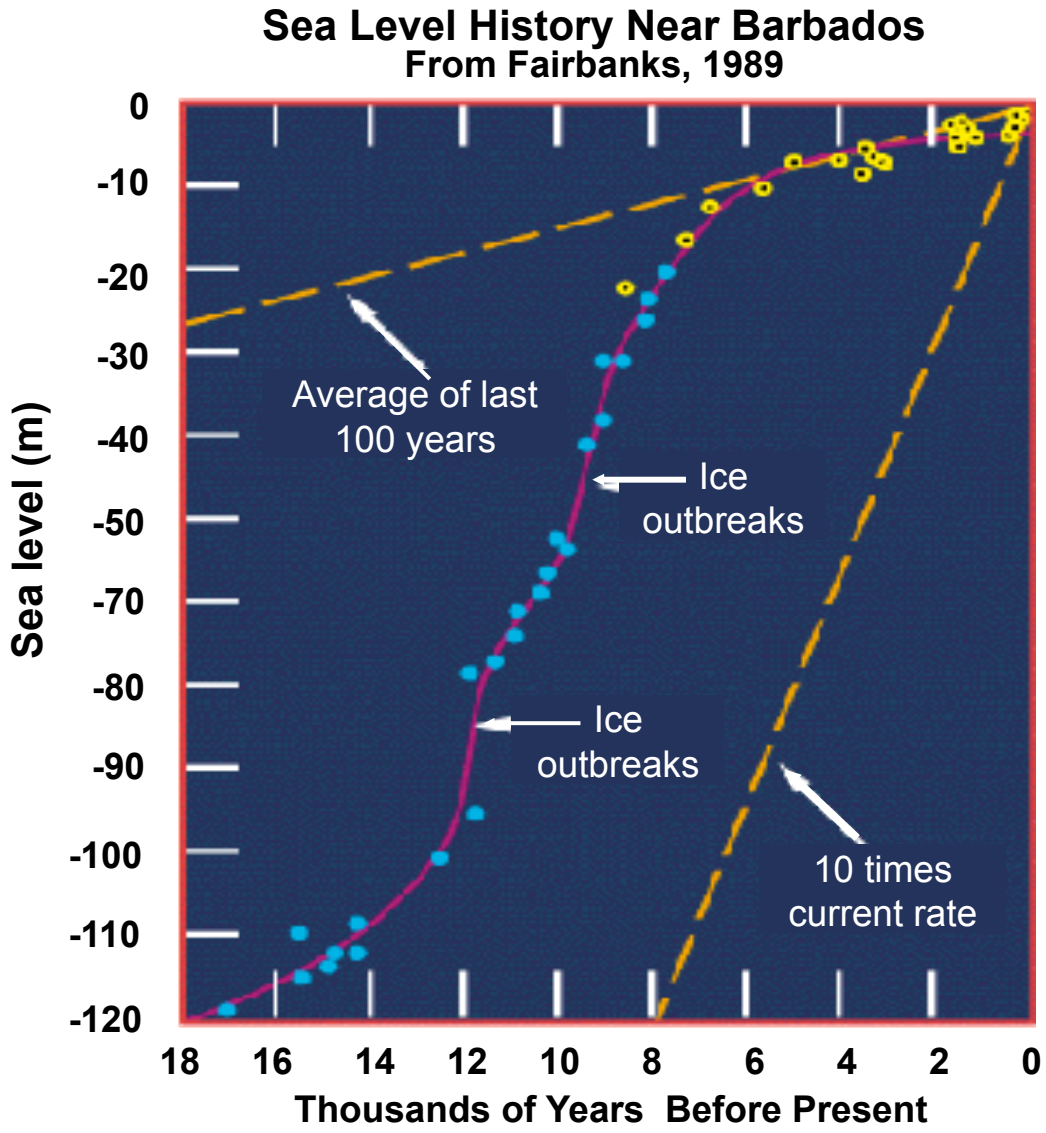
Past Sea Level Rise

- Last 14 years: ~3.5 mm/yr
- Last Century: ~1.8 mm/yr
- Historic evidence suggests past rates of 50 mm/yr
  - Associated with ice loss



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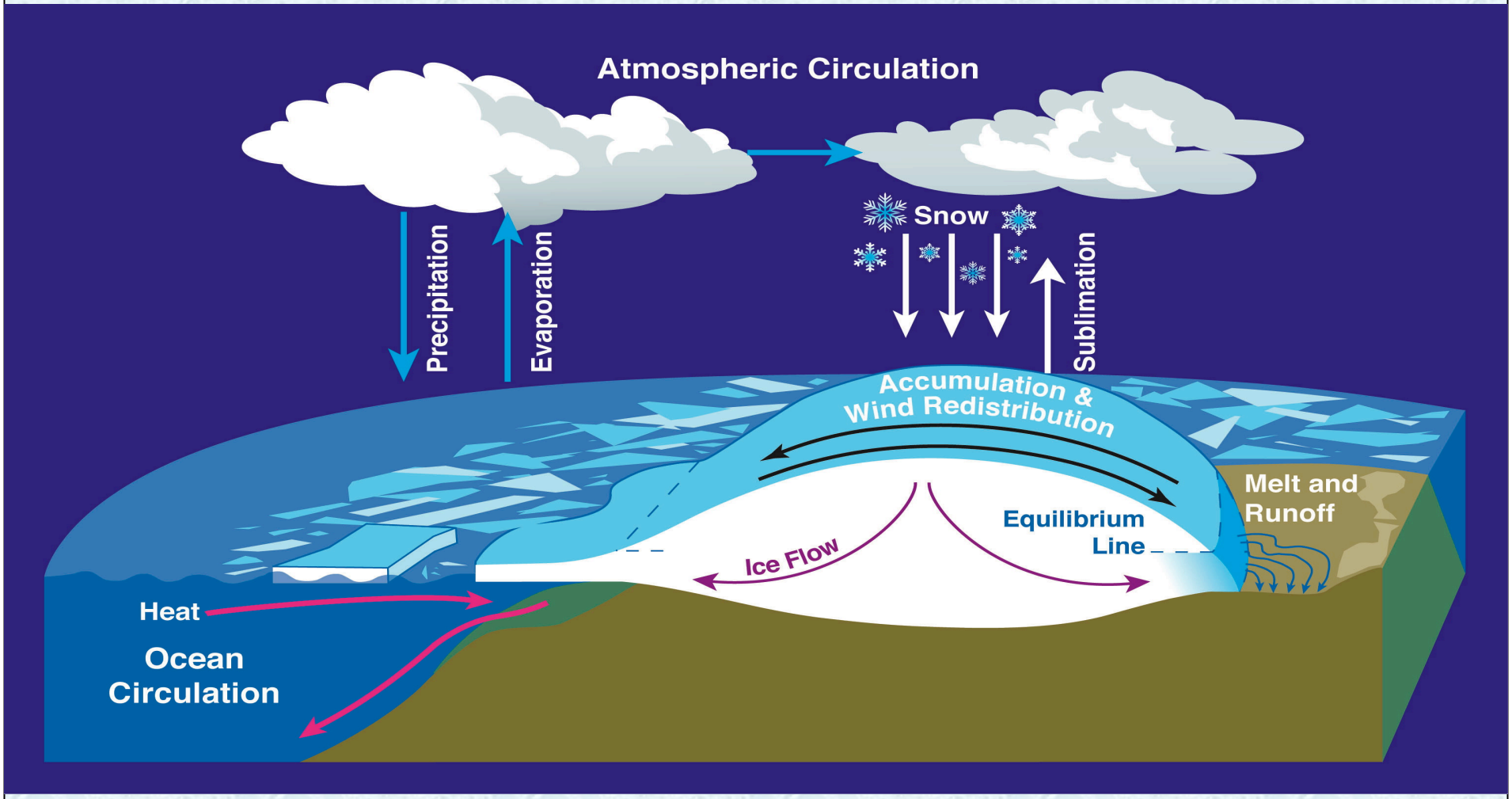
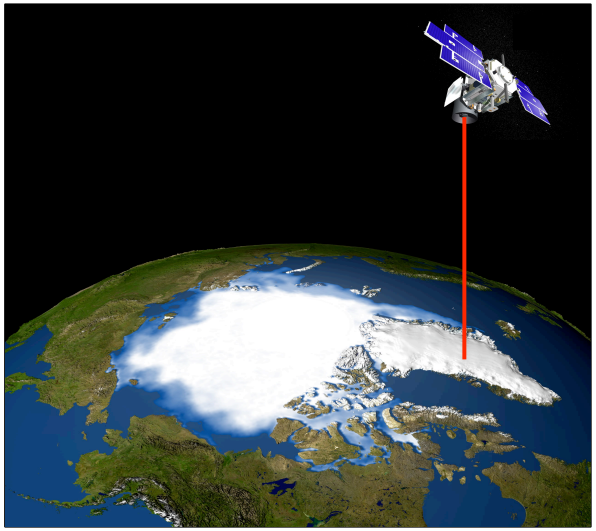
How Does and Ice Sheet Grow and Shrink?

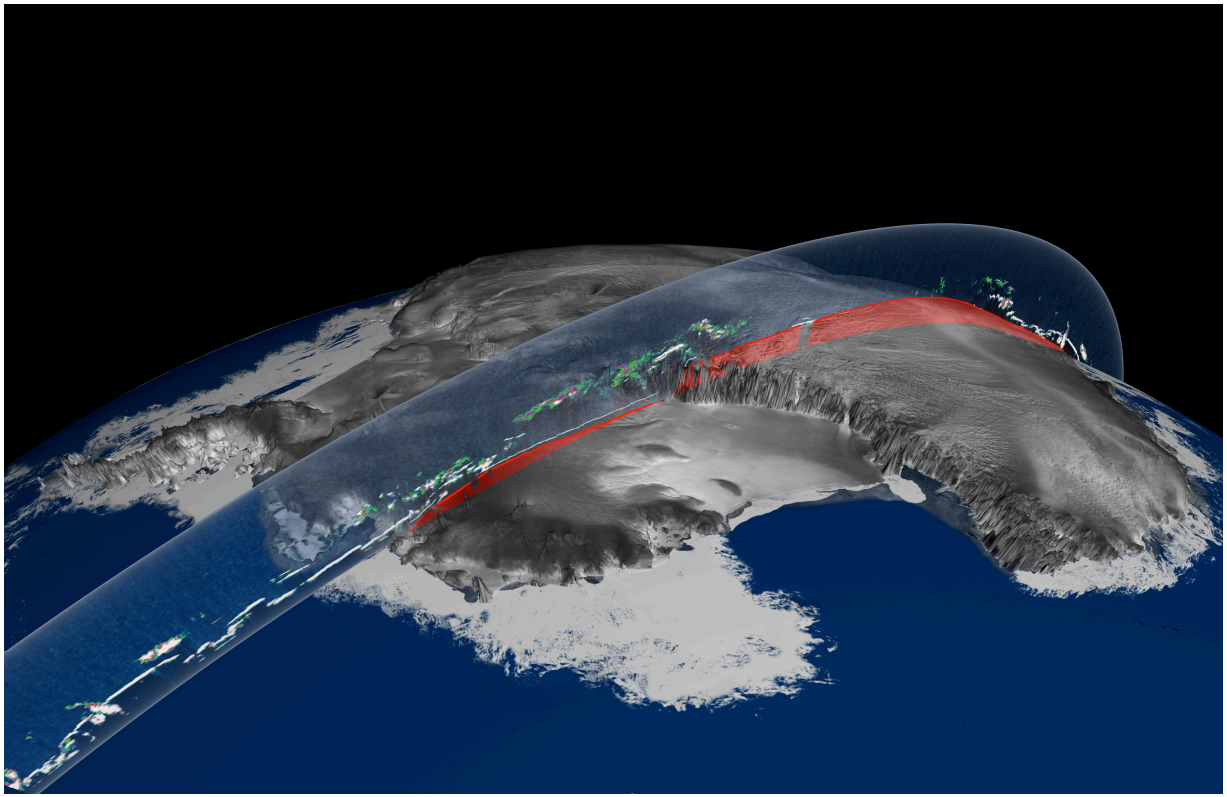


Warming temperatures increase melt, flow, AND Precipitation

Mass Balance Approaches

- Altimetry: infer mass balance from elevation changes





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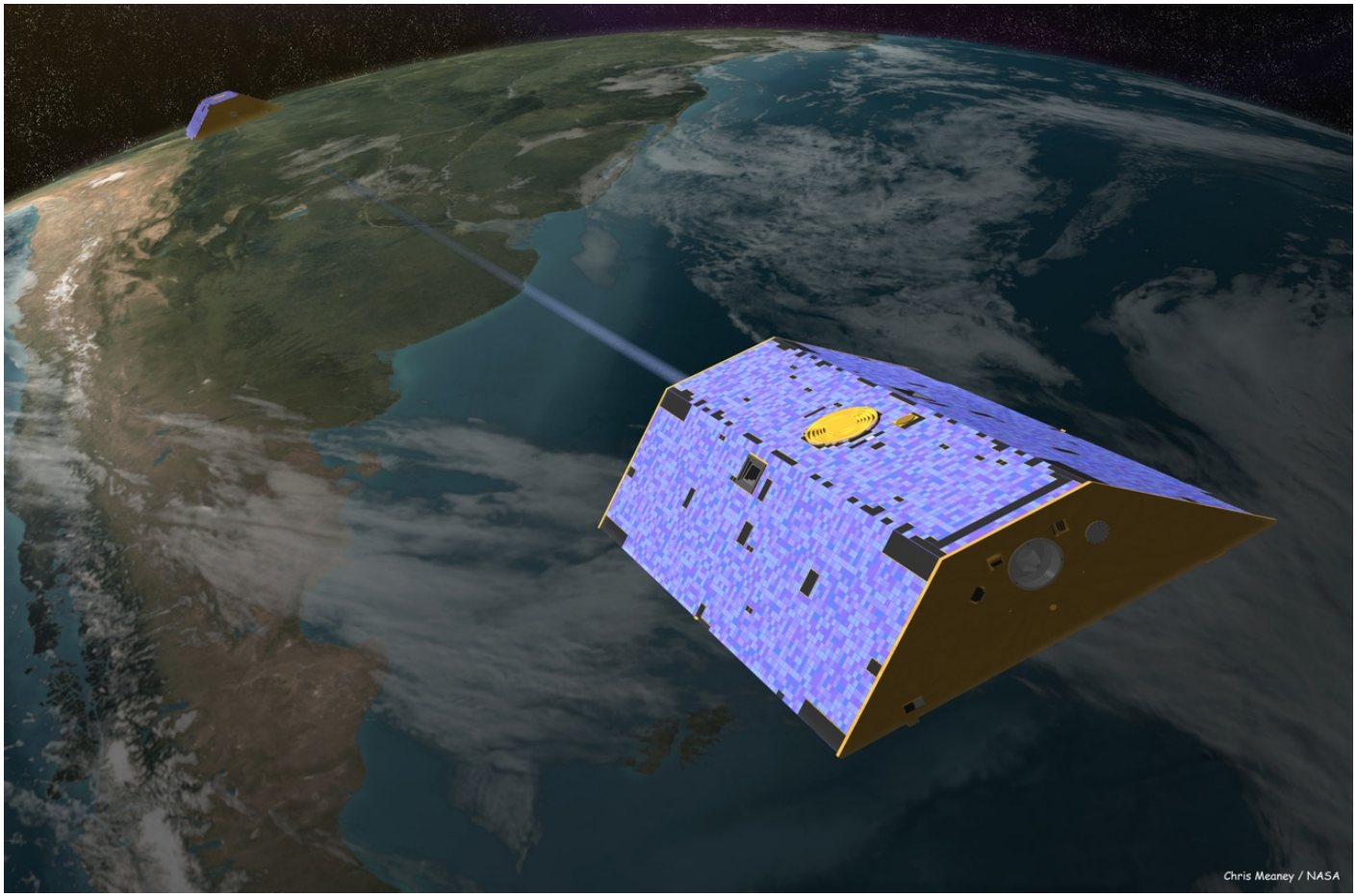
Mass Balance Approaches

- Gravity: infer mass balance from gravity changes



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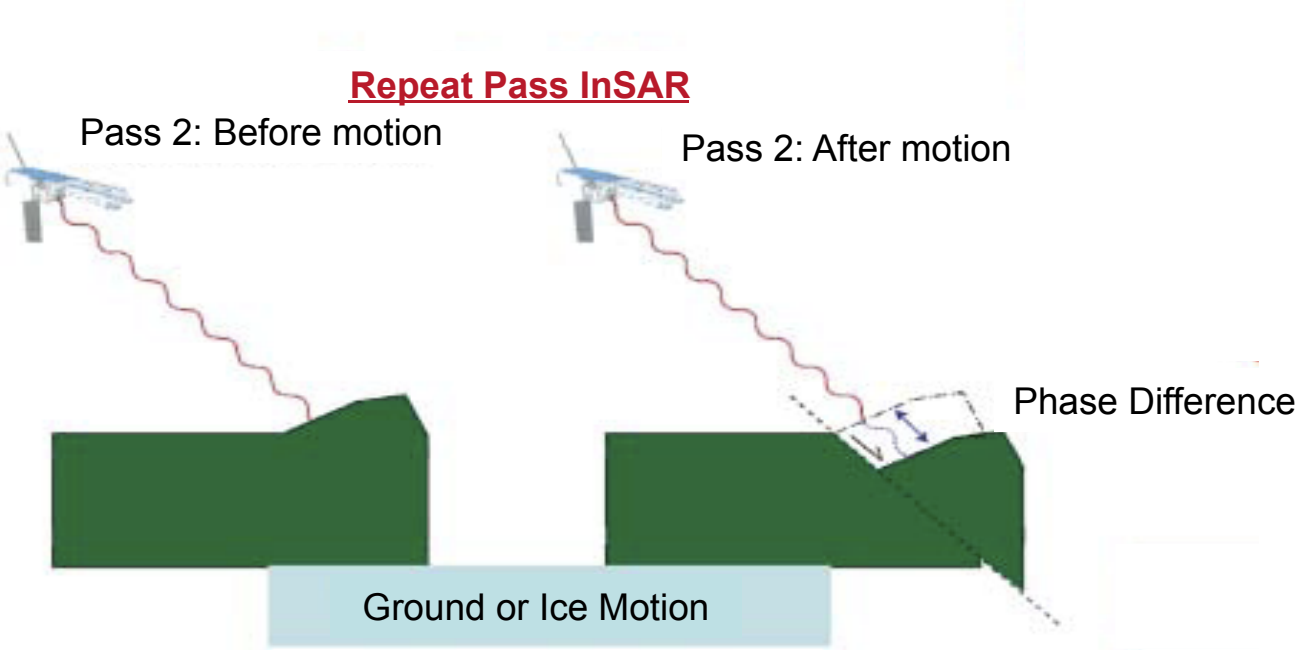
Mass Balance Approaches

- Flux Method: Assess net difference between mass input to mass output from observations and models of each component

Balance = Precipitation - Surface Ablation - Discharge

↑ Ice Cores & Models ↑ Models ↑ InSAR & others



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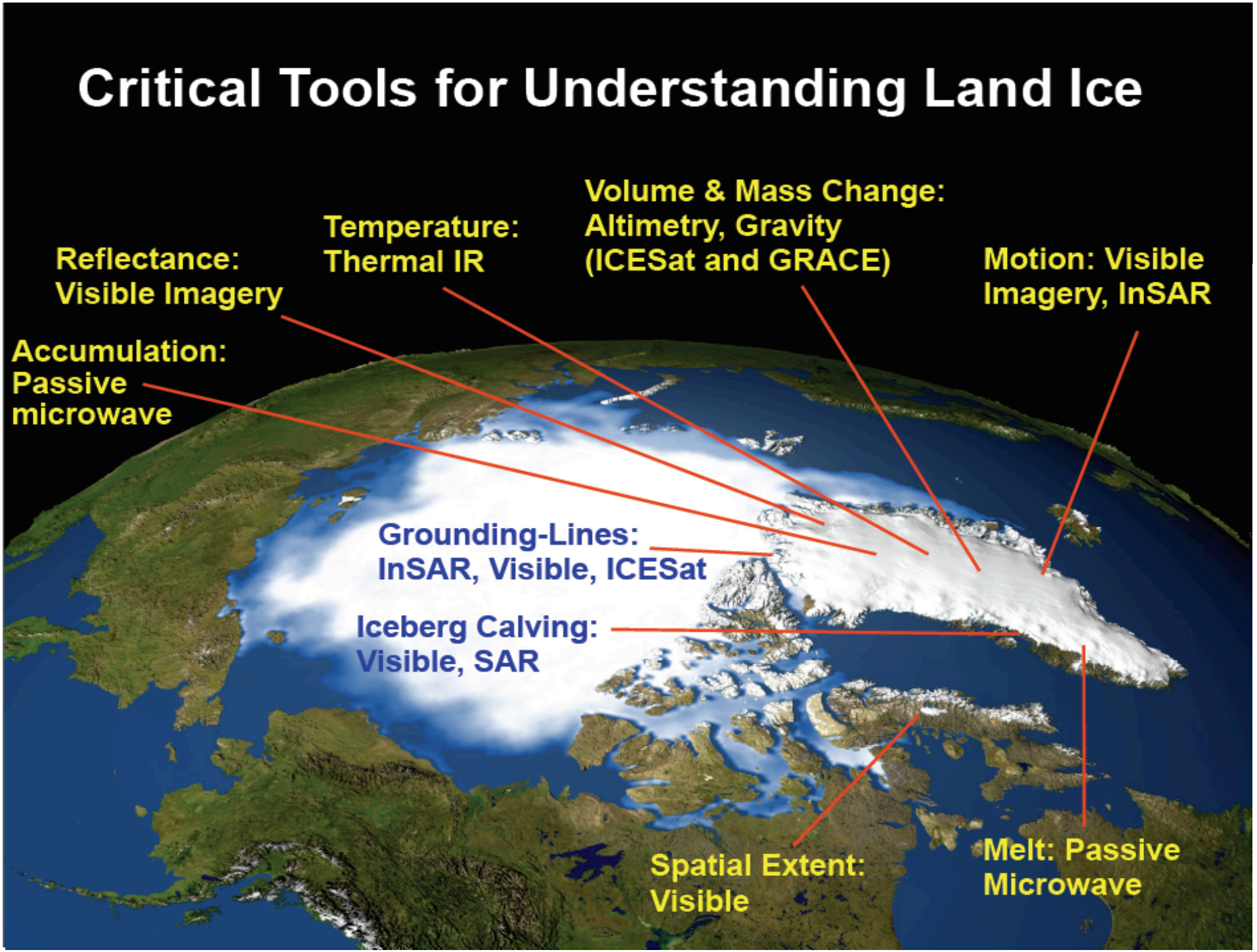
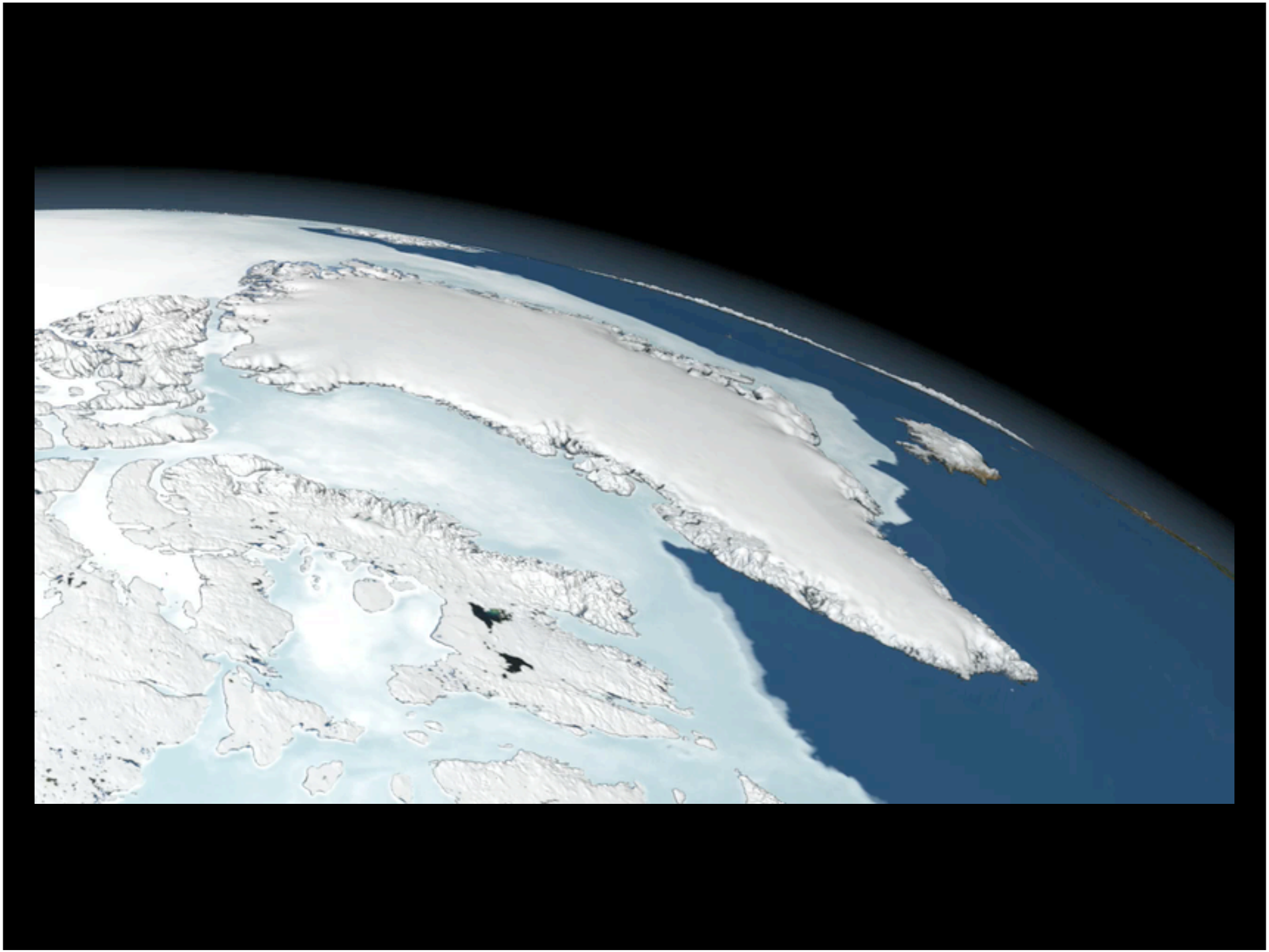
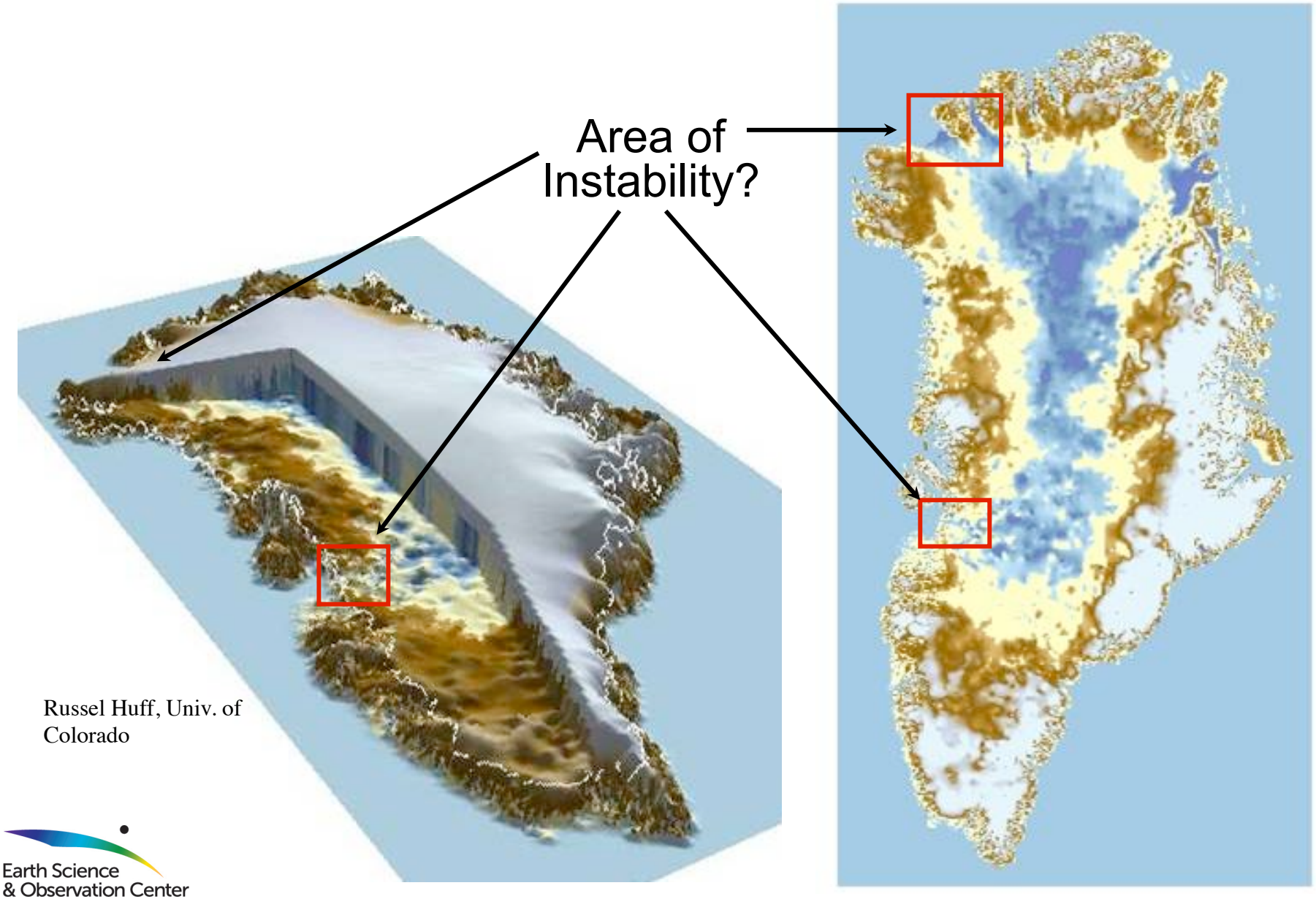

Critical Tools for Understanding Land Ice
Reflectance: Visible Imagery
Temperature: Thermal IR
Volume & Mass Change: Altimetry, Gravity (ICESat and GRACE)
Motion: Visible Imagery, InSAR
Accumulation: Passive microwave
Grounding-Lines: InSAR, Visible, ICESat
Iceberg Calving: Visible, SAR
Spatial Extent: Visible
Melt: Passive Microwave



Sub-Glacial Topography



Russel Huff, Univ. of Colorado

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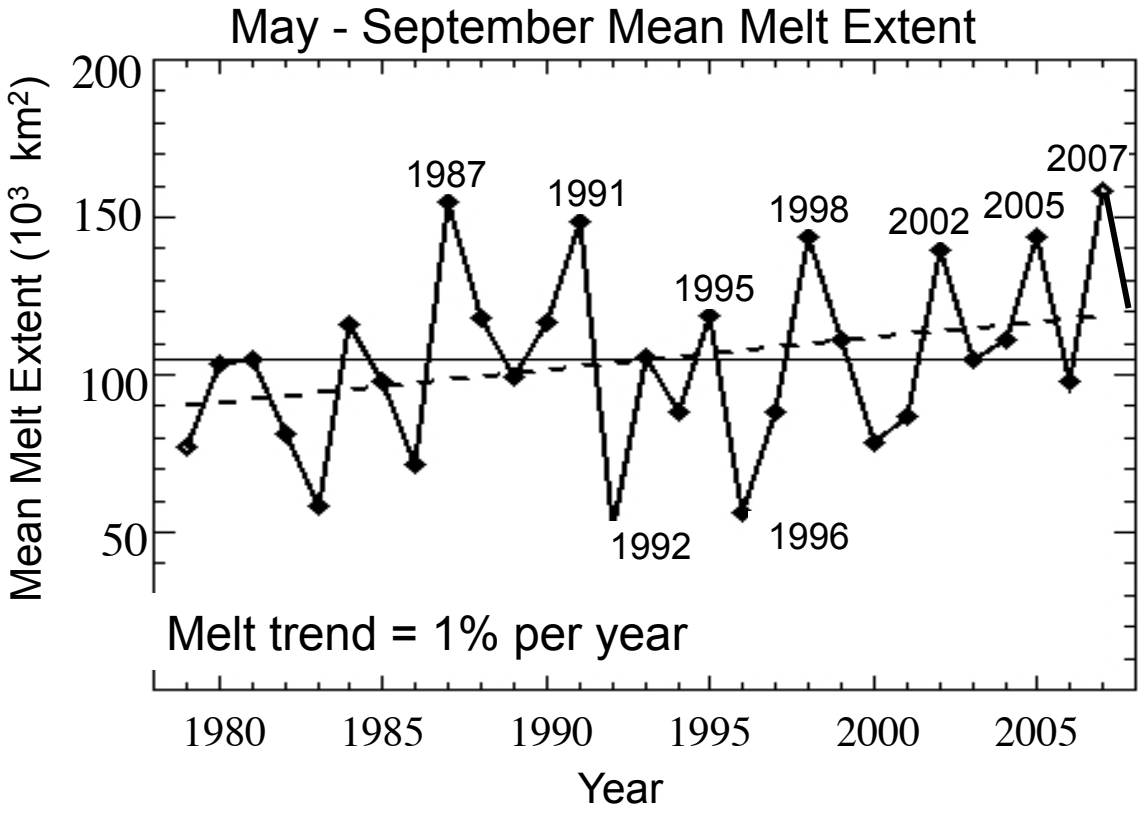
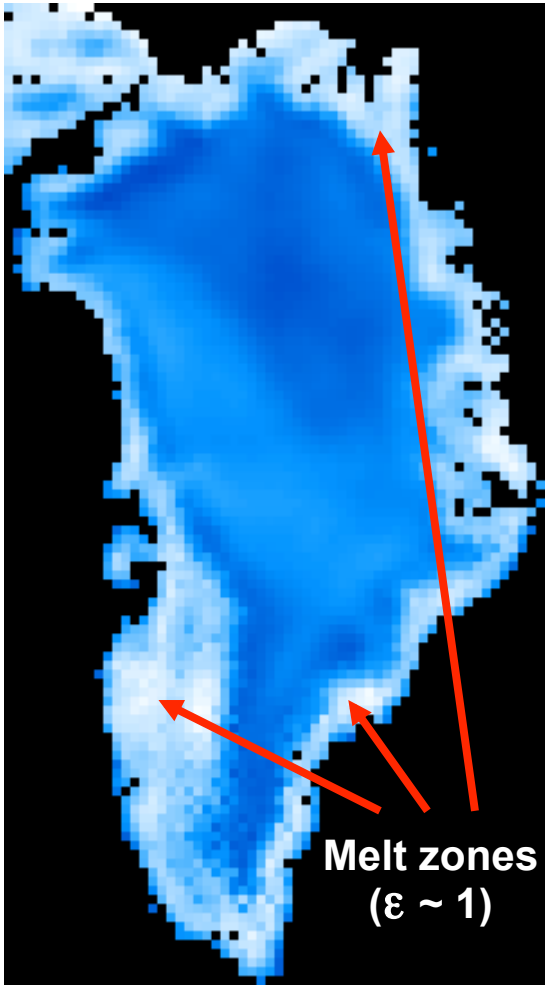
Increasing Greenland Melt



~33% melt increase from 1979 to 2008

What happens to all that melt water?



SSM/I 19 GHz Horizontal
July 7th, 1995

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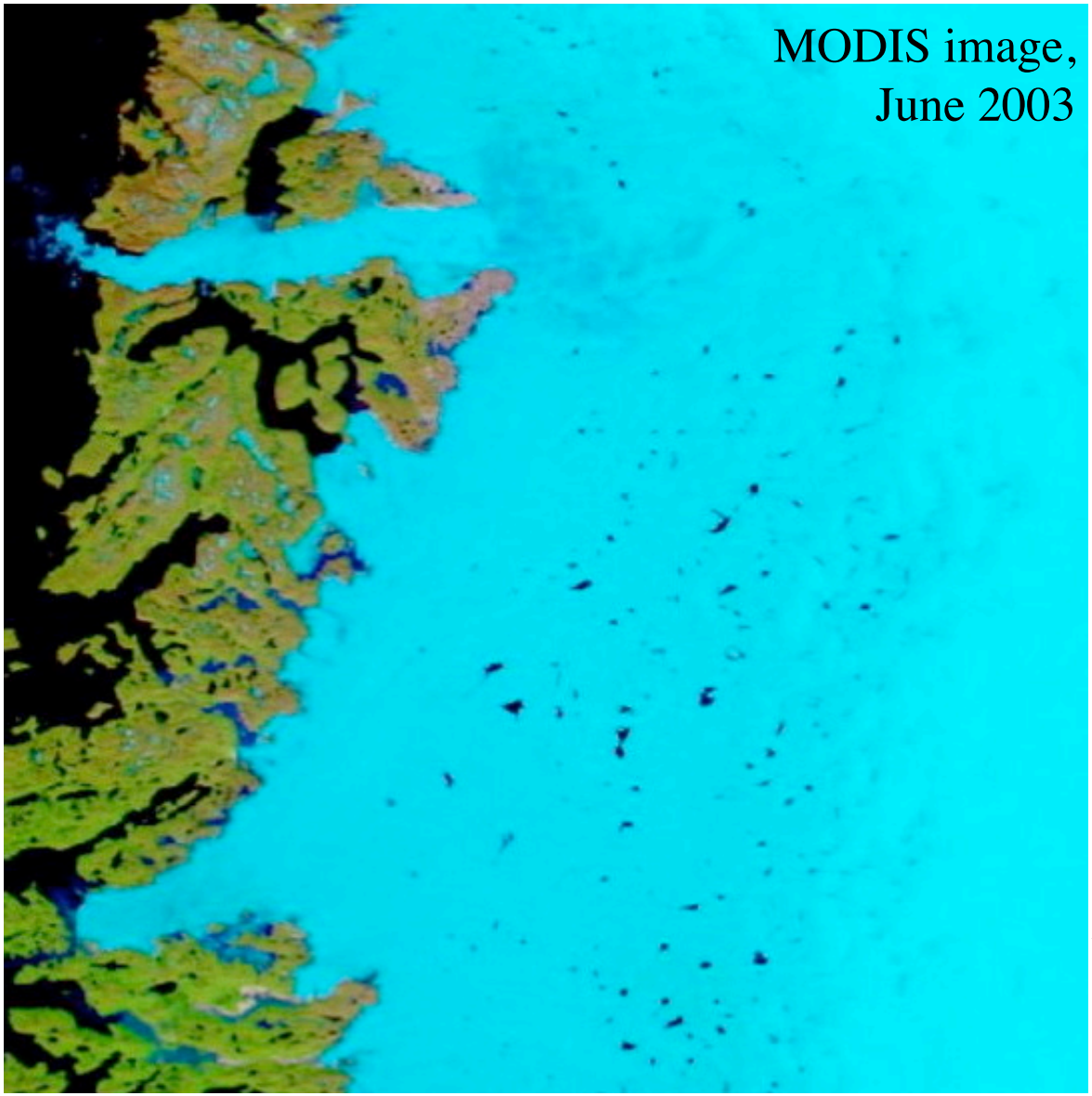
Ice Sheet Melt Lakes



- Hundreds form in topographic basins within ablation zone
- Drain very rapidly
- Kilometers wide
- Meters deep

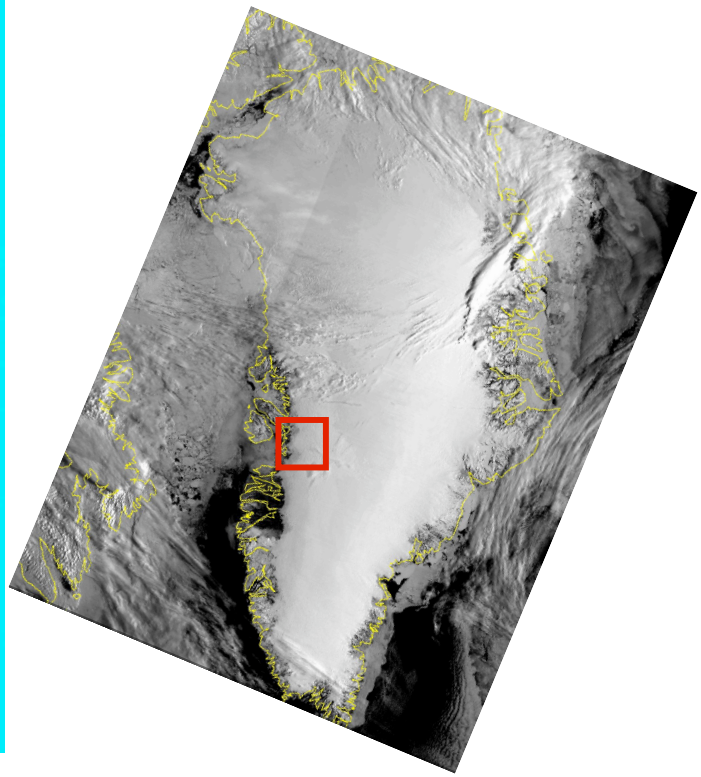



Photo © Greenpeace

Meltwater Accelerates Ice Flow

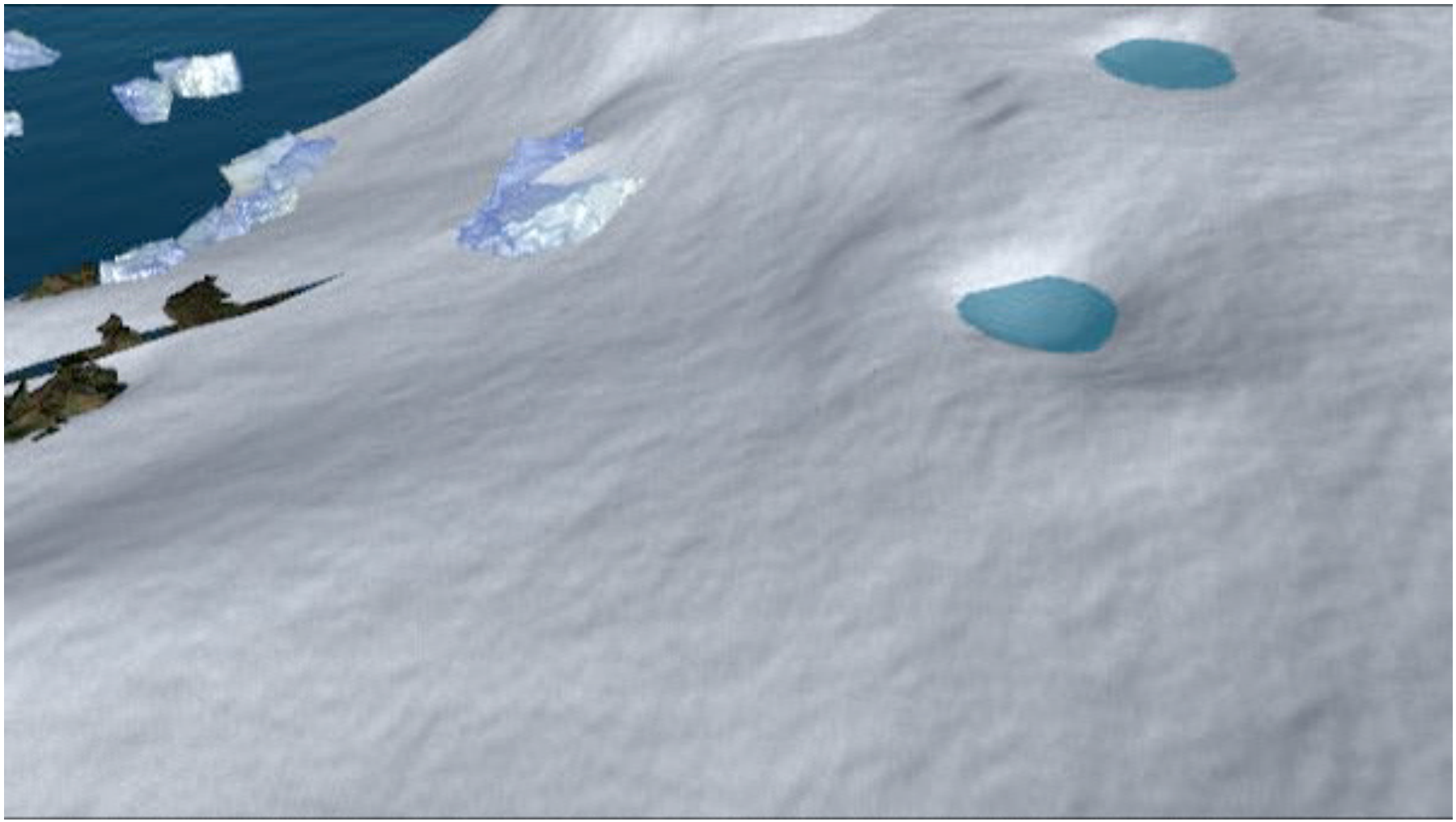
Photo © Scott McGhee

Photo: R. Braithwaite © AAAS, Science, vol. 297, No. 5579

Photo by Ian Joughin,
Univ. of Washington

Photo by Ian Joughin, Univ. of Washington

Meltwater Accelerates Ice Flow



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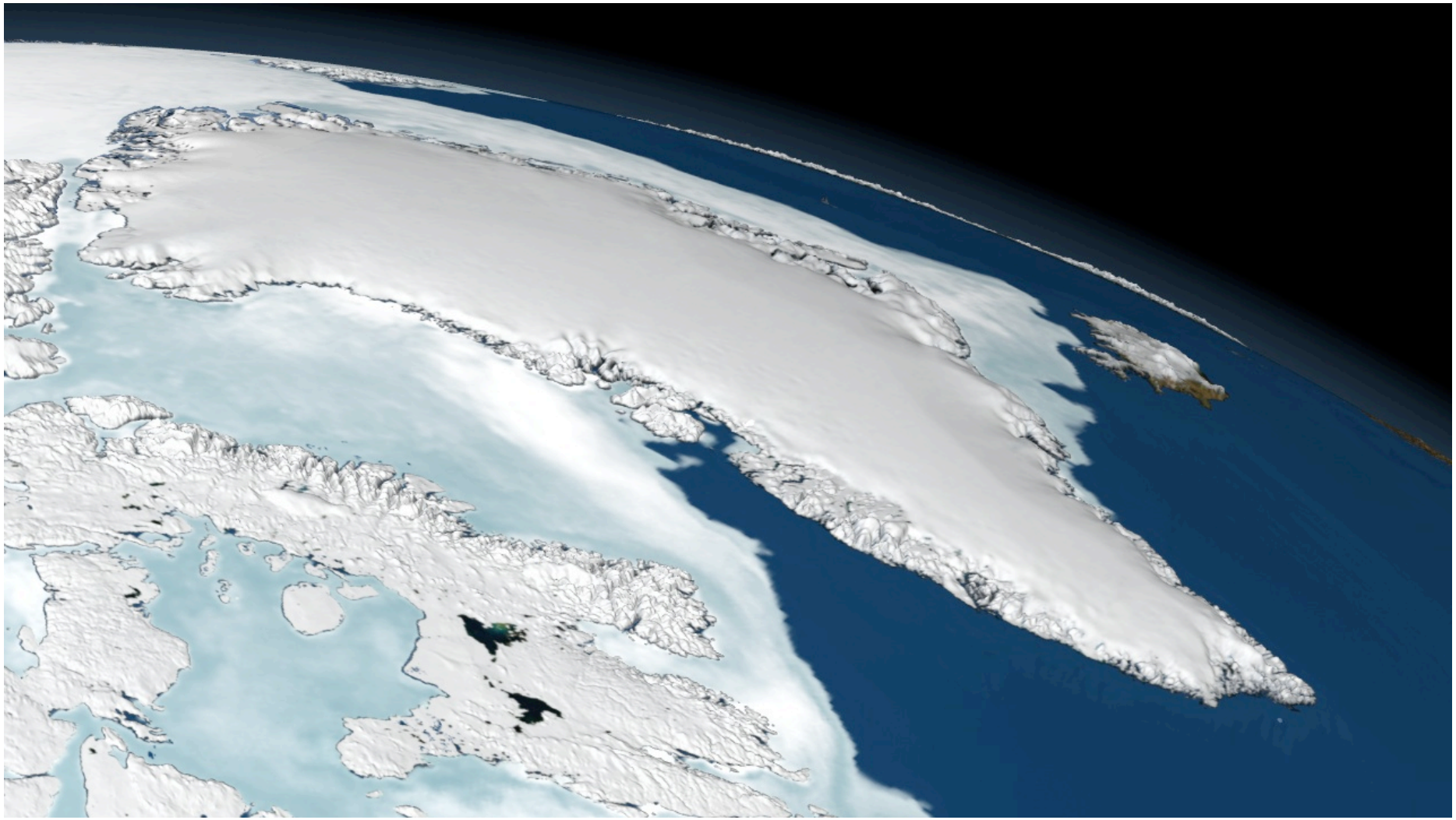
So How Much is Greenland Contributing to Sea Level Rise?



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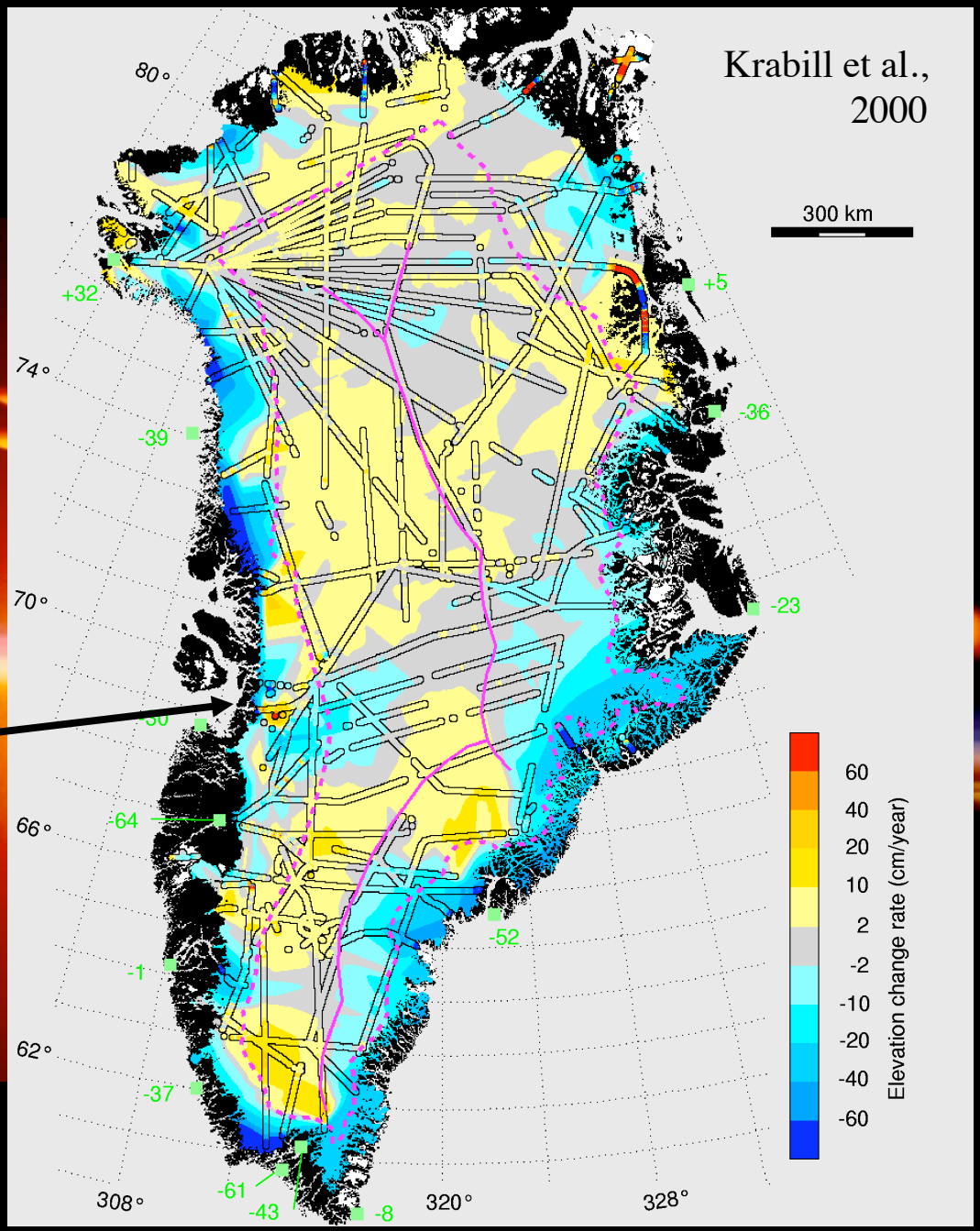
In the Beginning…

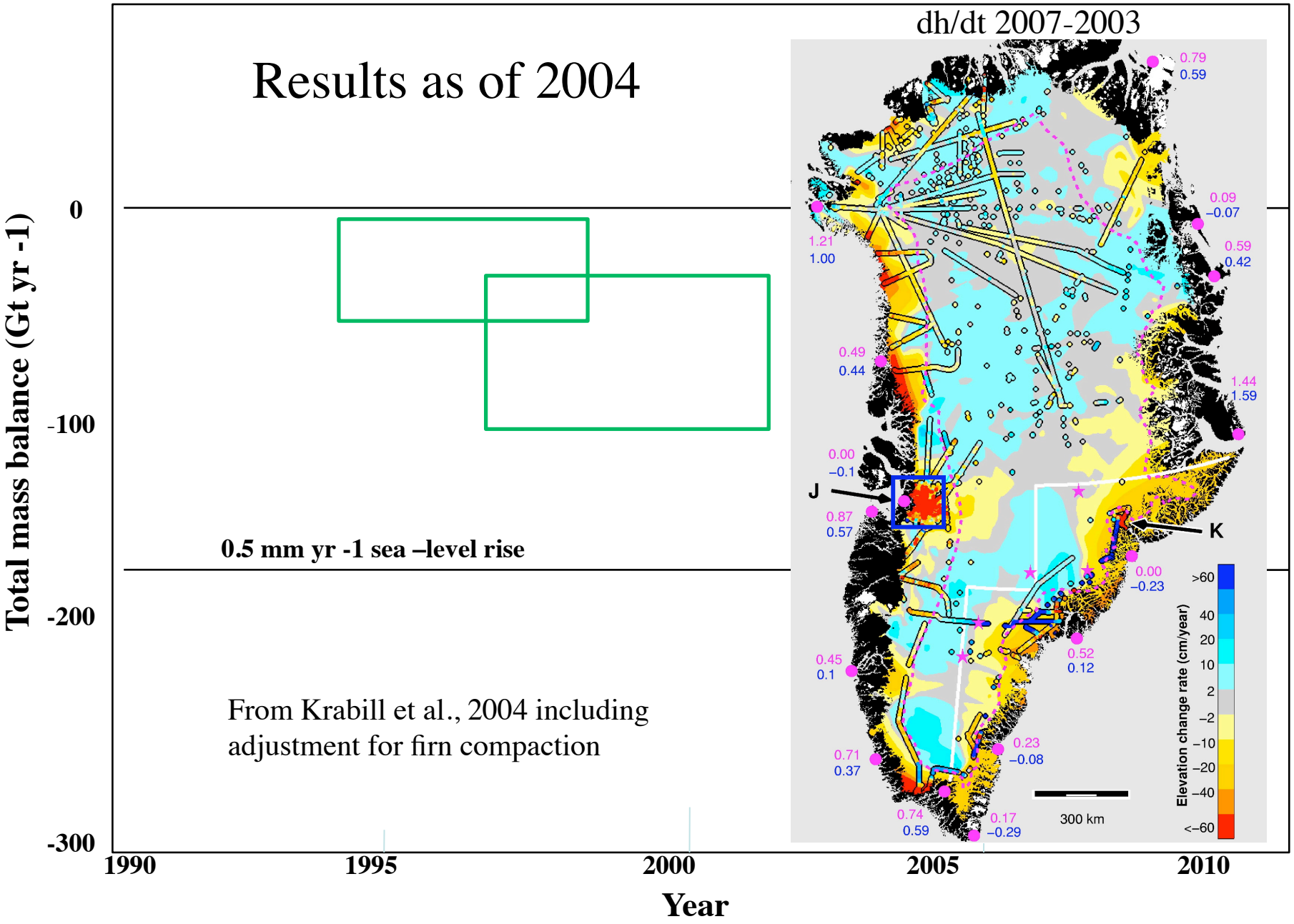
… there was Krabill.

- First observationally-based ice sheet mass balance estimate: covers 1993/4-1998/9
- Growth in interior
- Thinning at margins
- Jakobshavn Thickening
- -46 GT mass balance

… And it was good

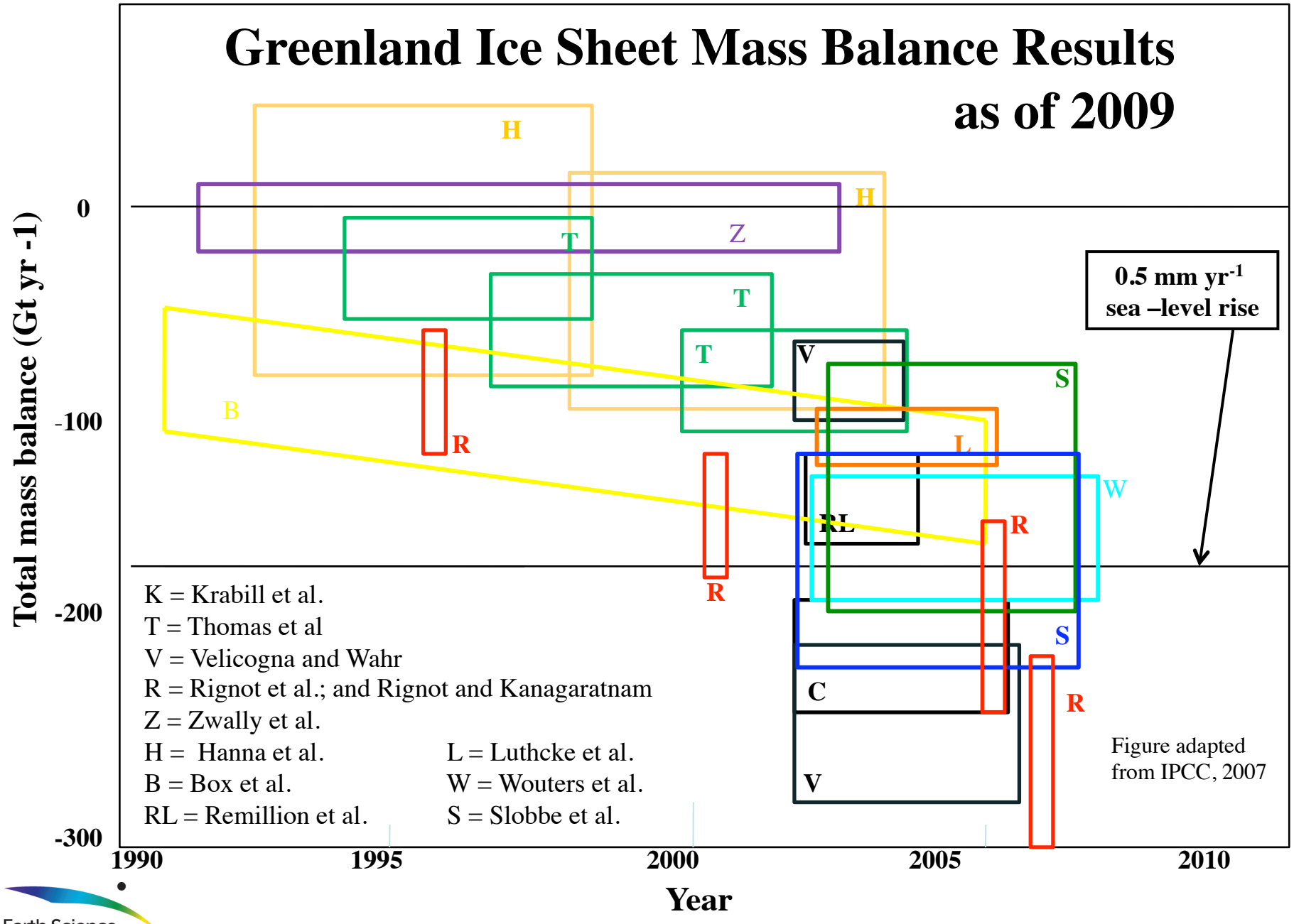


Results as of 2004



A man with one watch knows what time it is. A man with two watches is never sure.

Lee Segal



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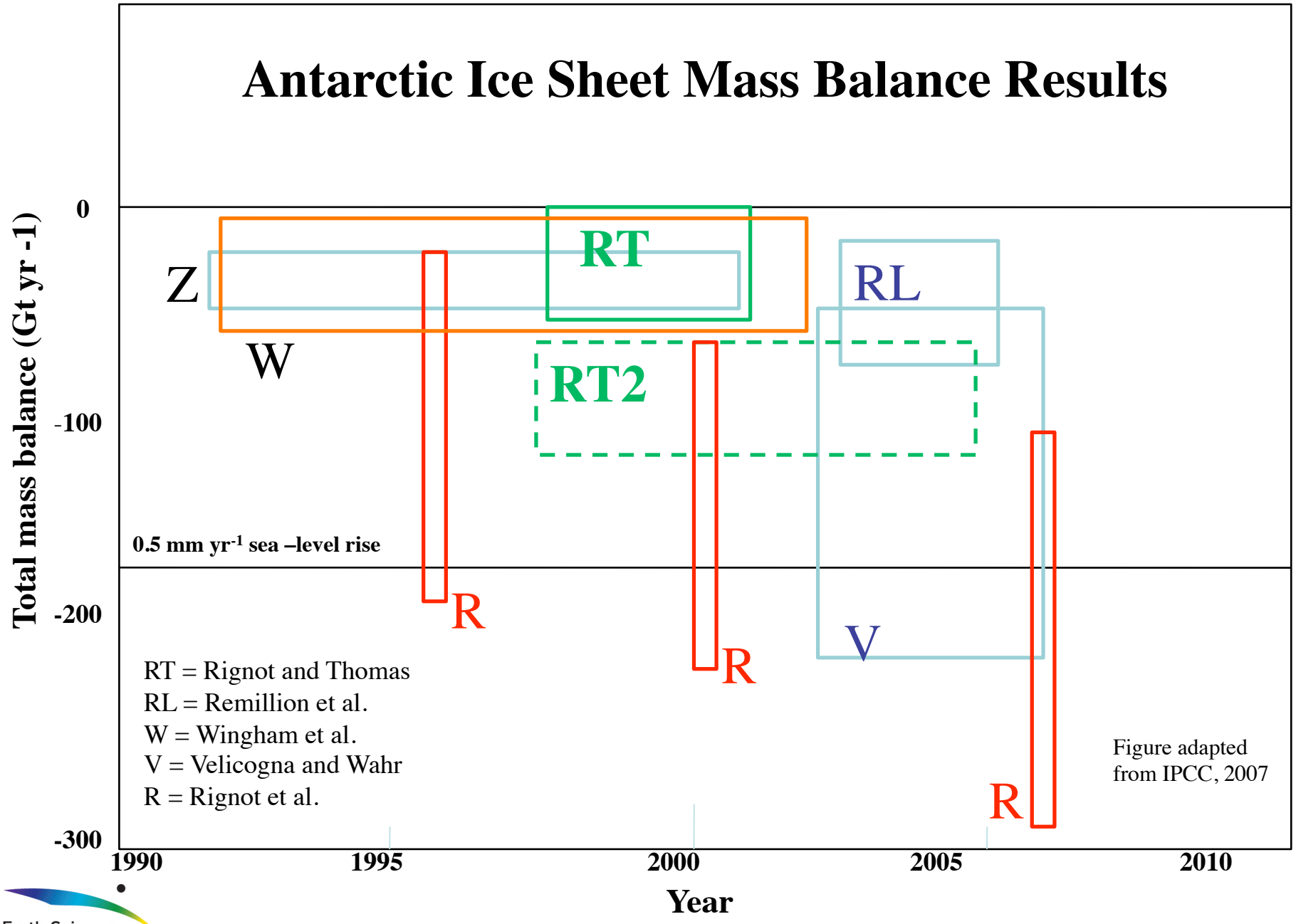

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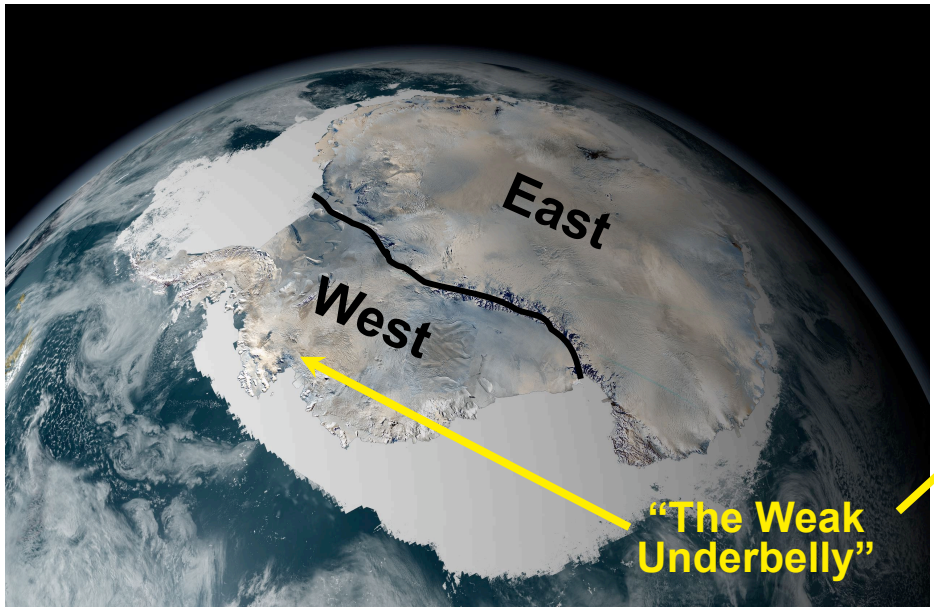
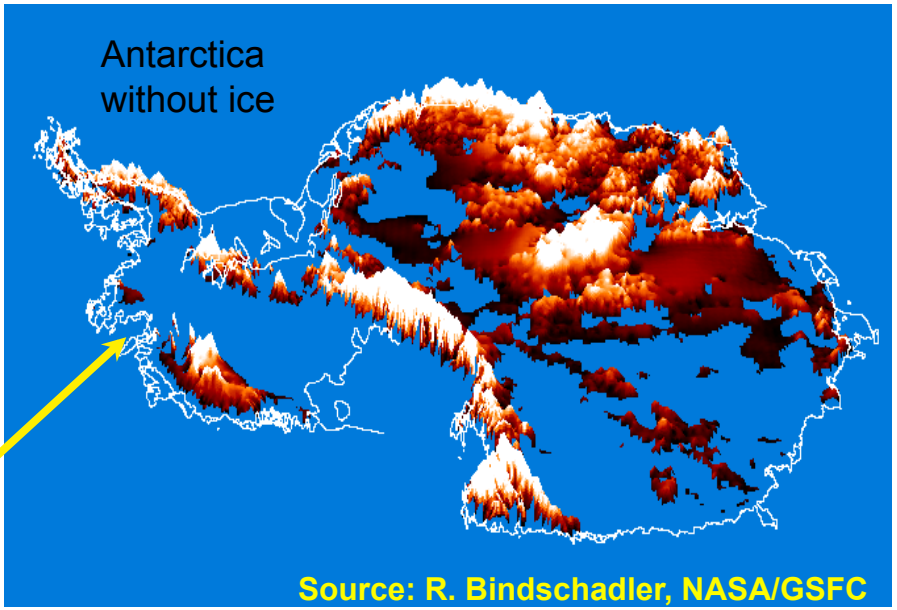
The Antarctic Ice Sheet





- 60 m sea level equivalent (SLE)
- Temperatures well below freezing
- West Antarctic ice sheet (~3.3 m SLE) rests on a soft bed that is below sea level
- **Unstable?**

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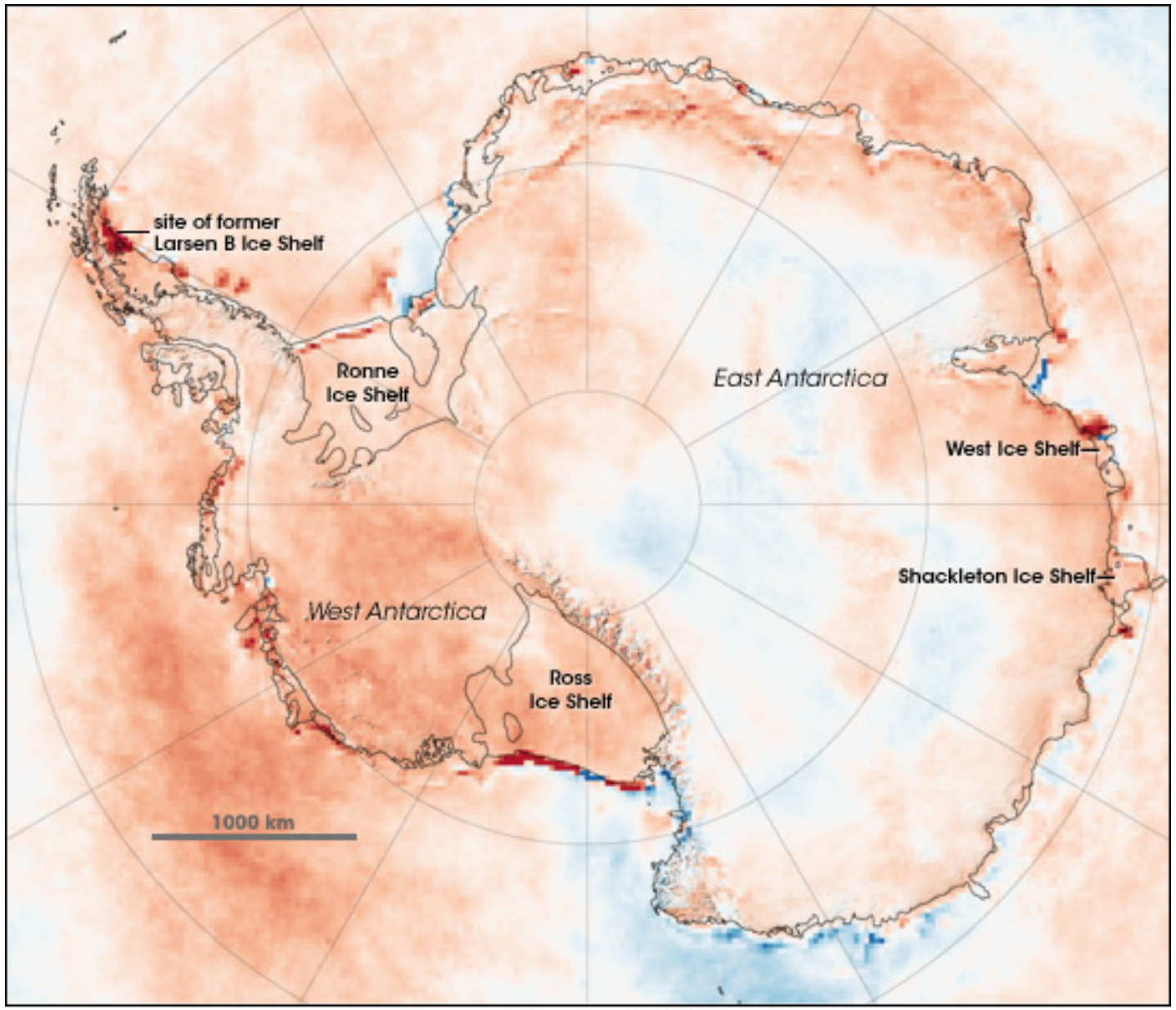
Antarctic Surface Temperature trends: 1981-2007 (derived from AVHRR)



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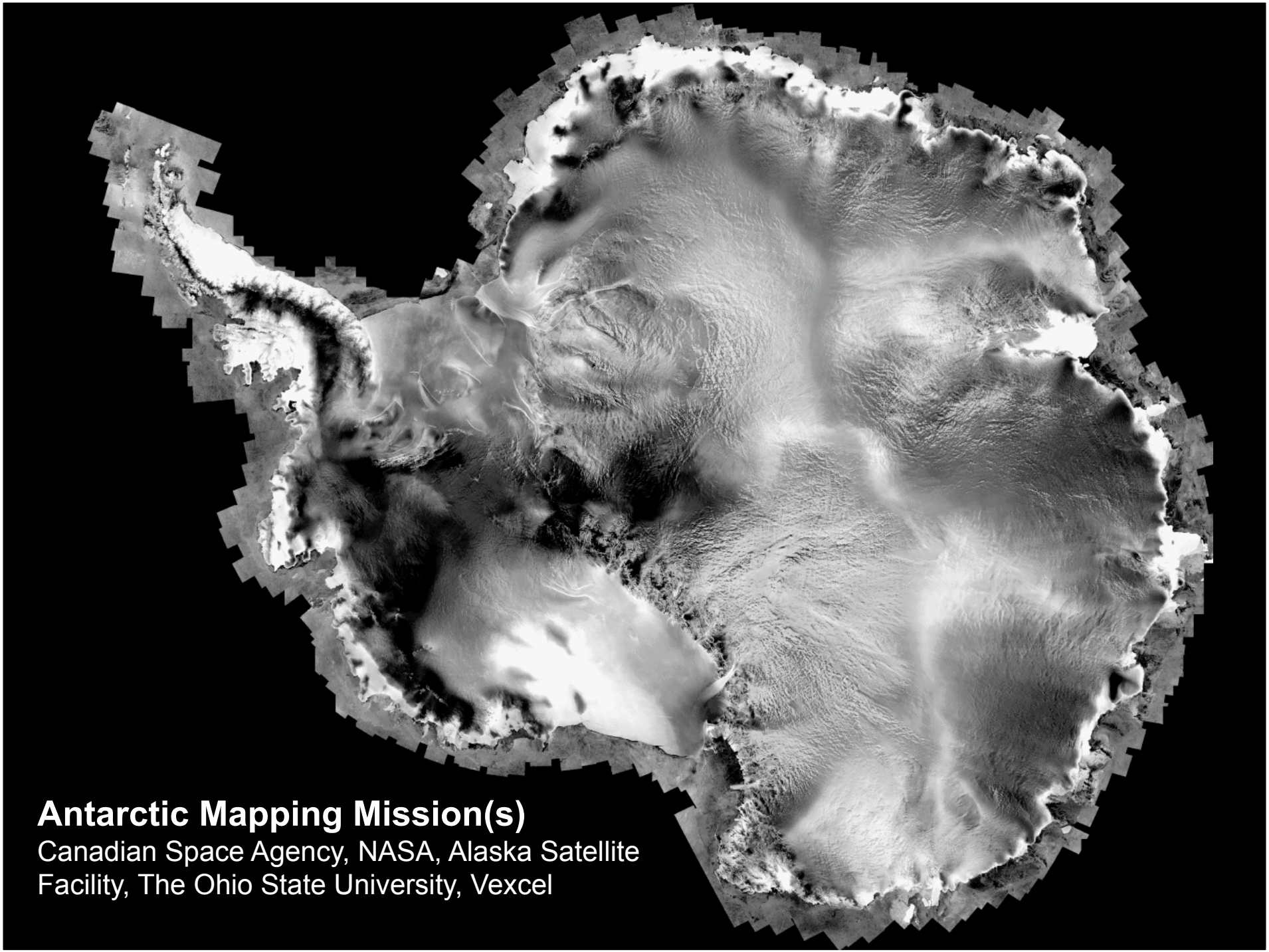
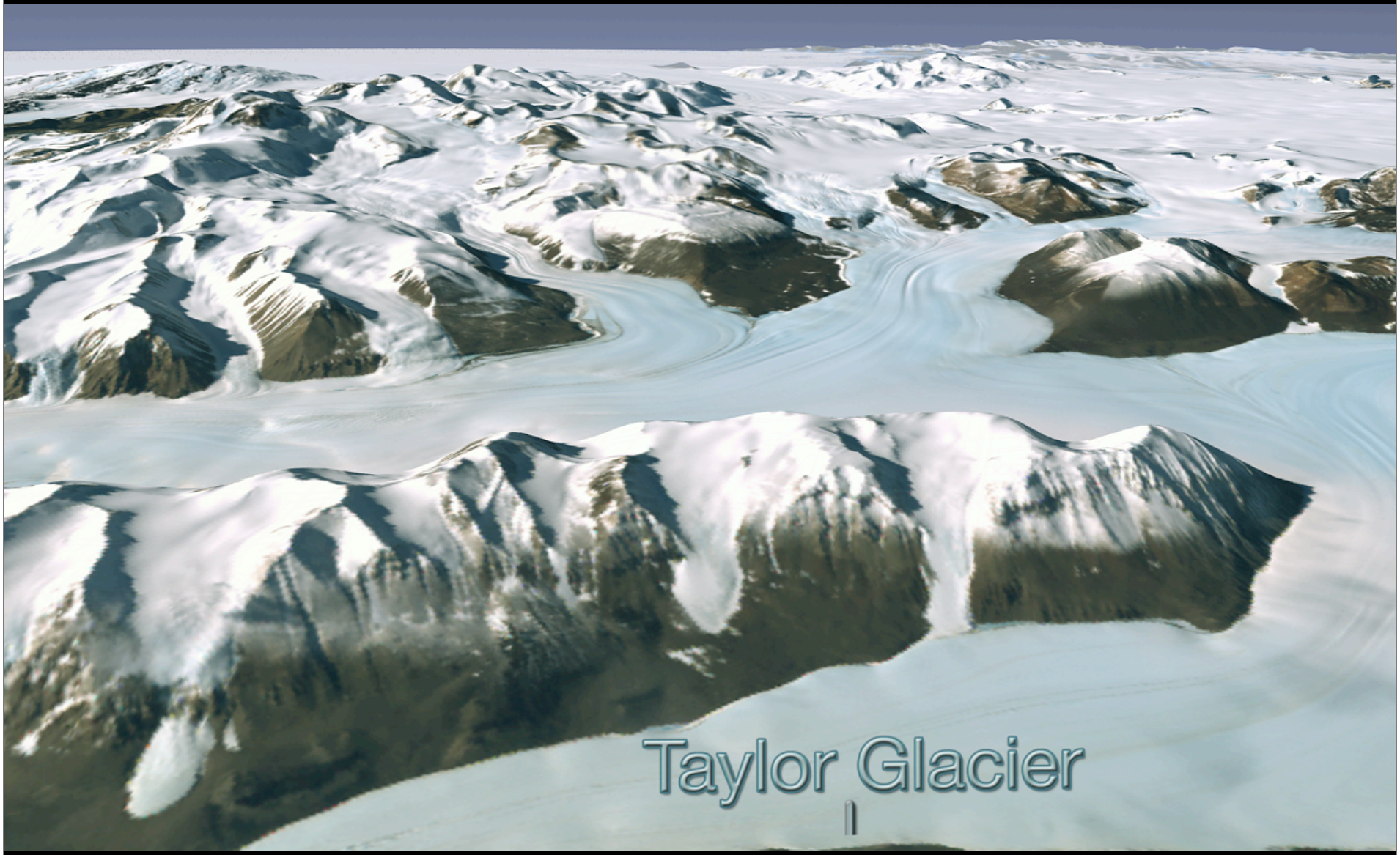
J. Comiso, GSFC



Antarctic Mapping Mission(s)

Canadian Space Agency, NASA, Alaska Satellite Facility, The Ohio State University, Vexcel

Landsat Image Mosaic of Antarctica



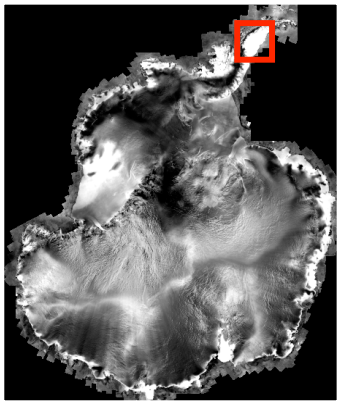
NASA

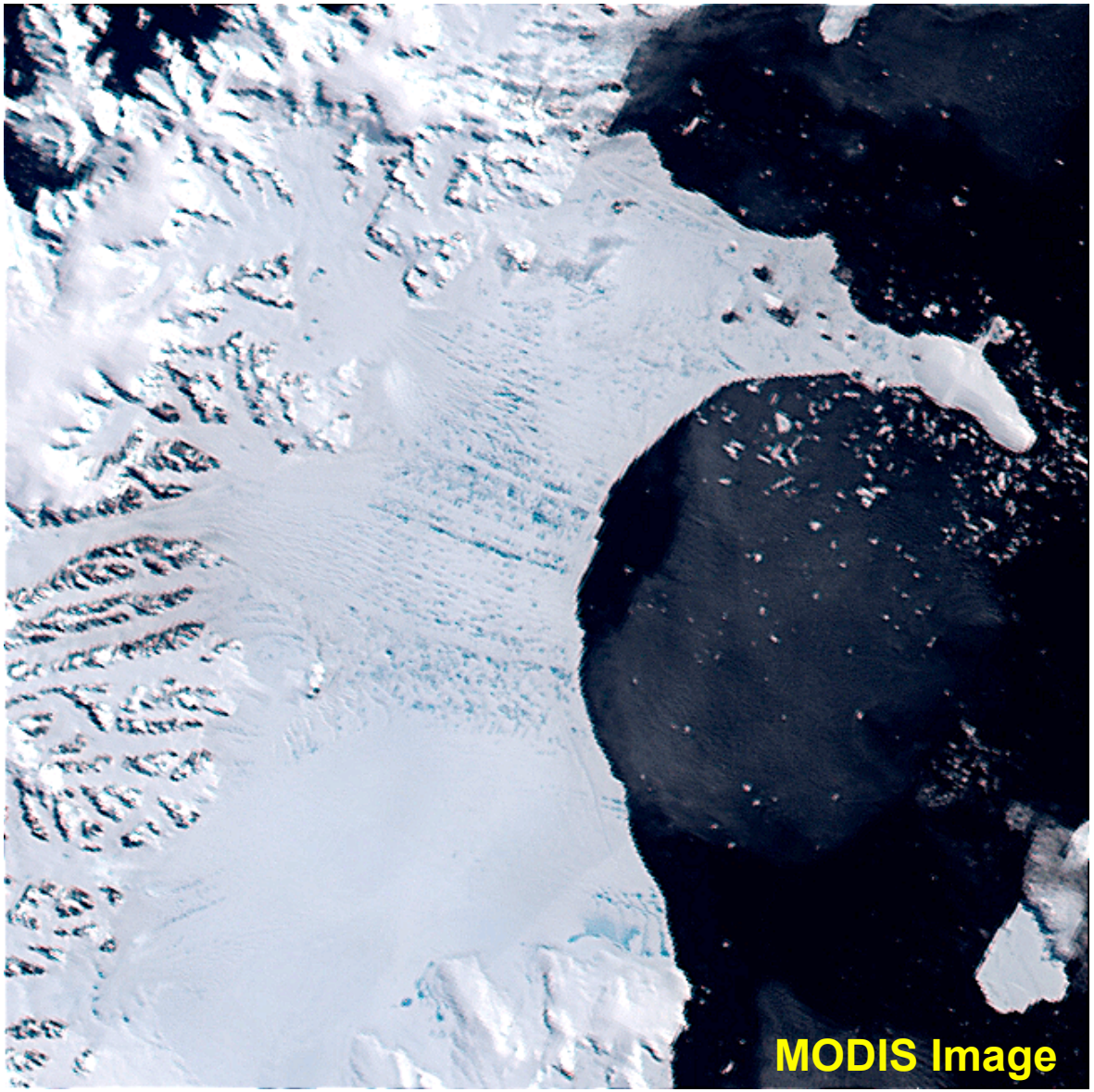
NSF

USGS
science for a changing world

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Larsen B Break-up 2002





January 31

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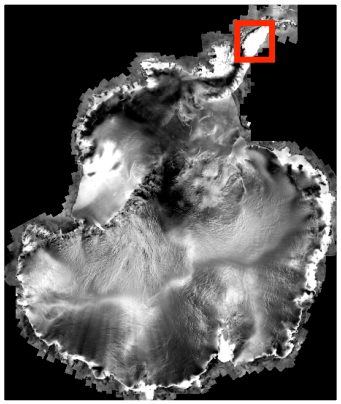
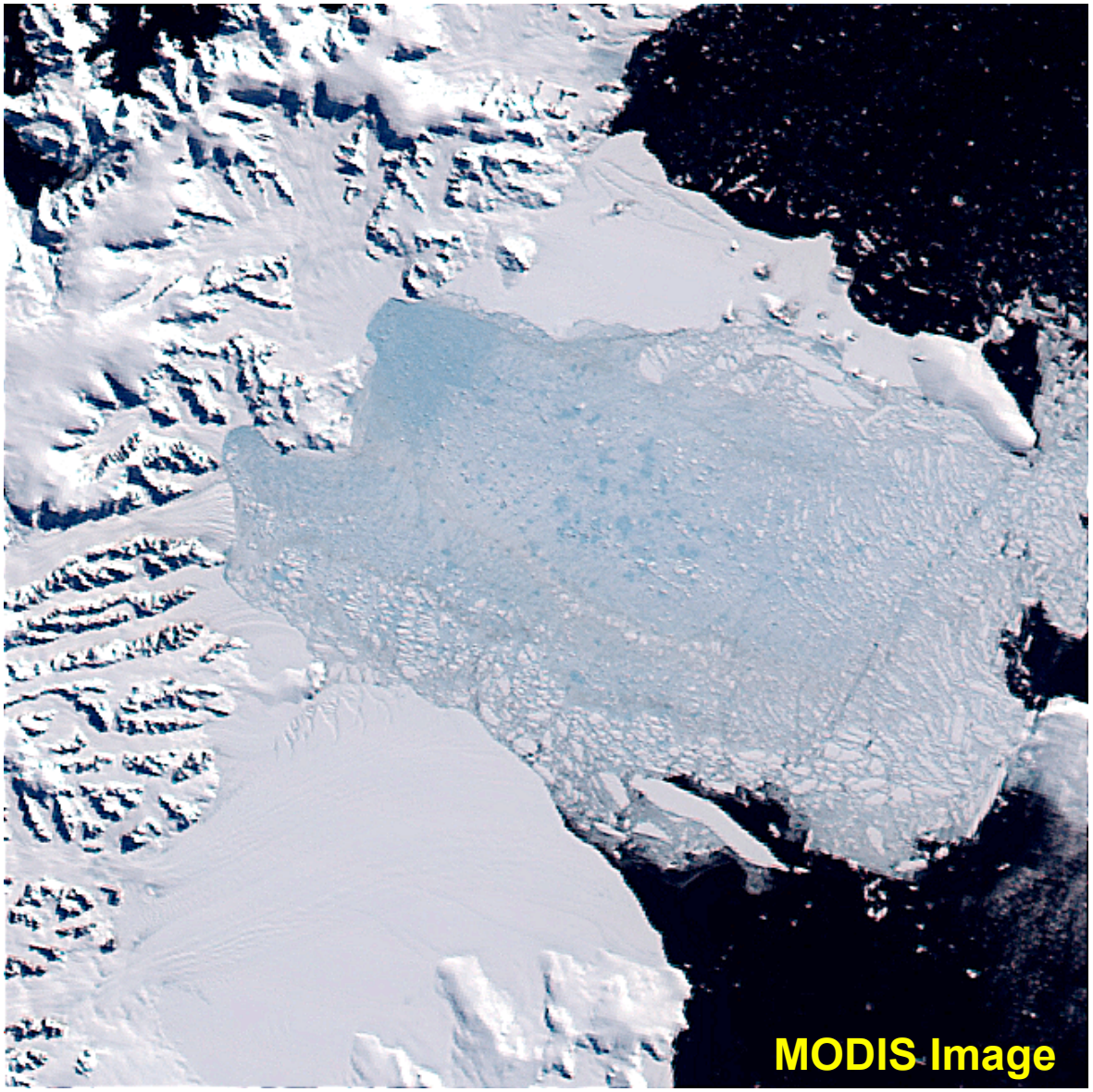
Ted Scambos, NSIDC

Larsen B Break-up 2002





March 17

10,000 years of ice gone in one month!

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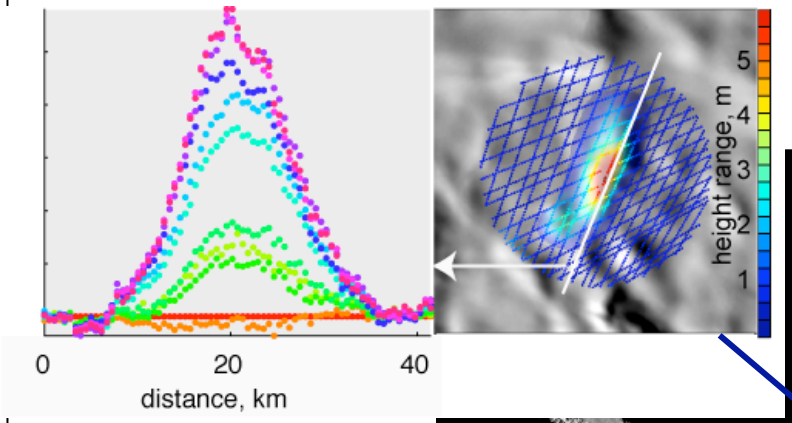
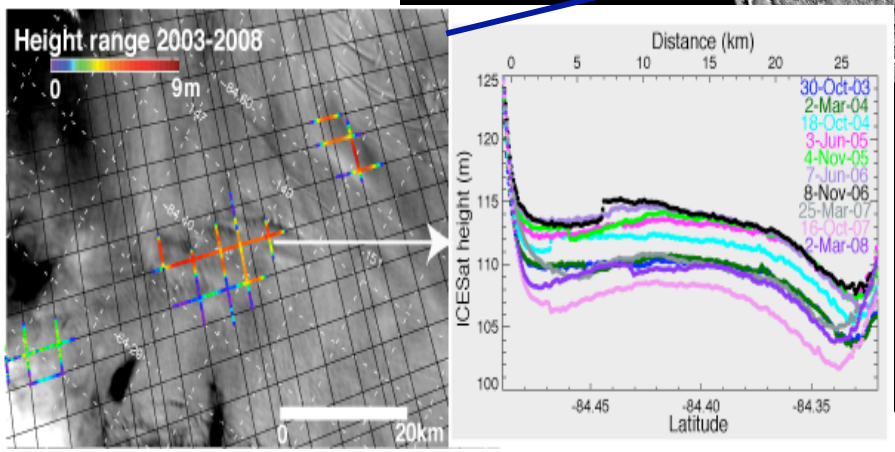
Ted Scambos, NSIDC

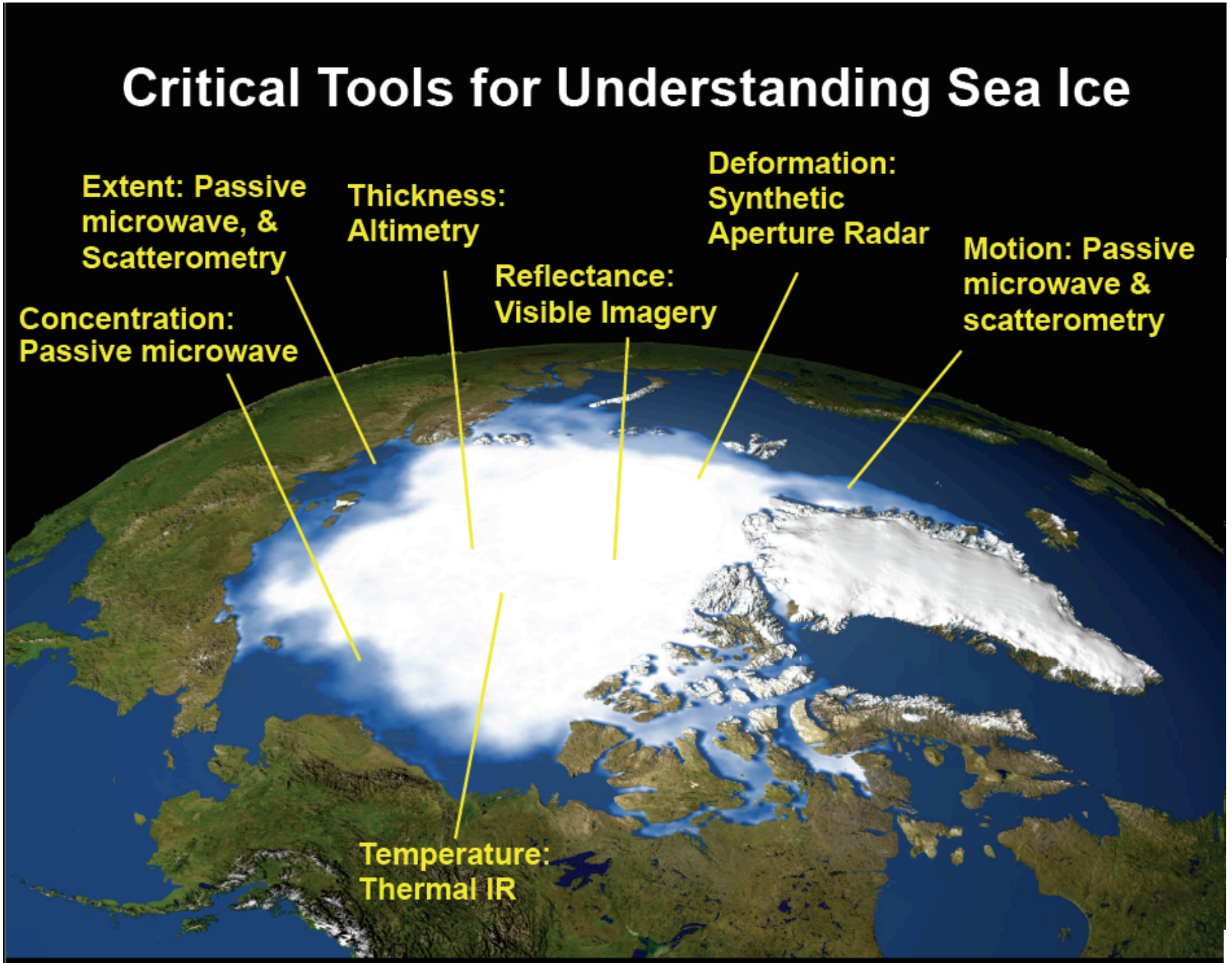
Antarctic Subglacial Lakes



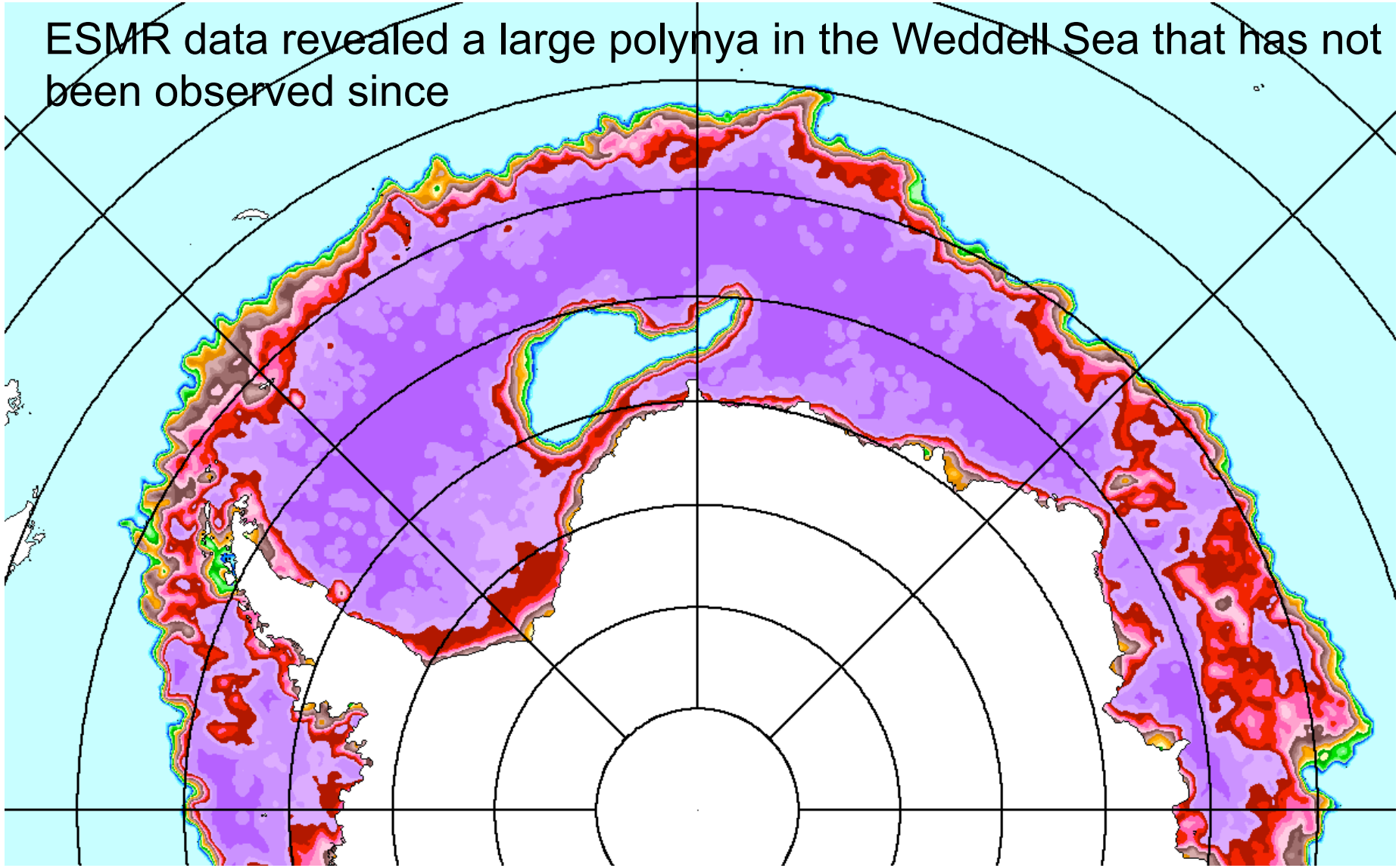
Source:
Fricker and
Scambos, 2009;
Smith et al., 2009



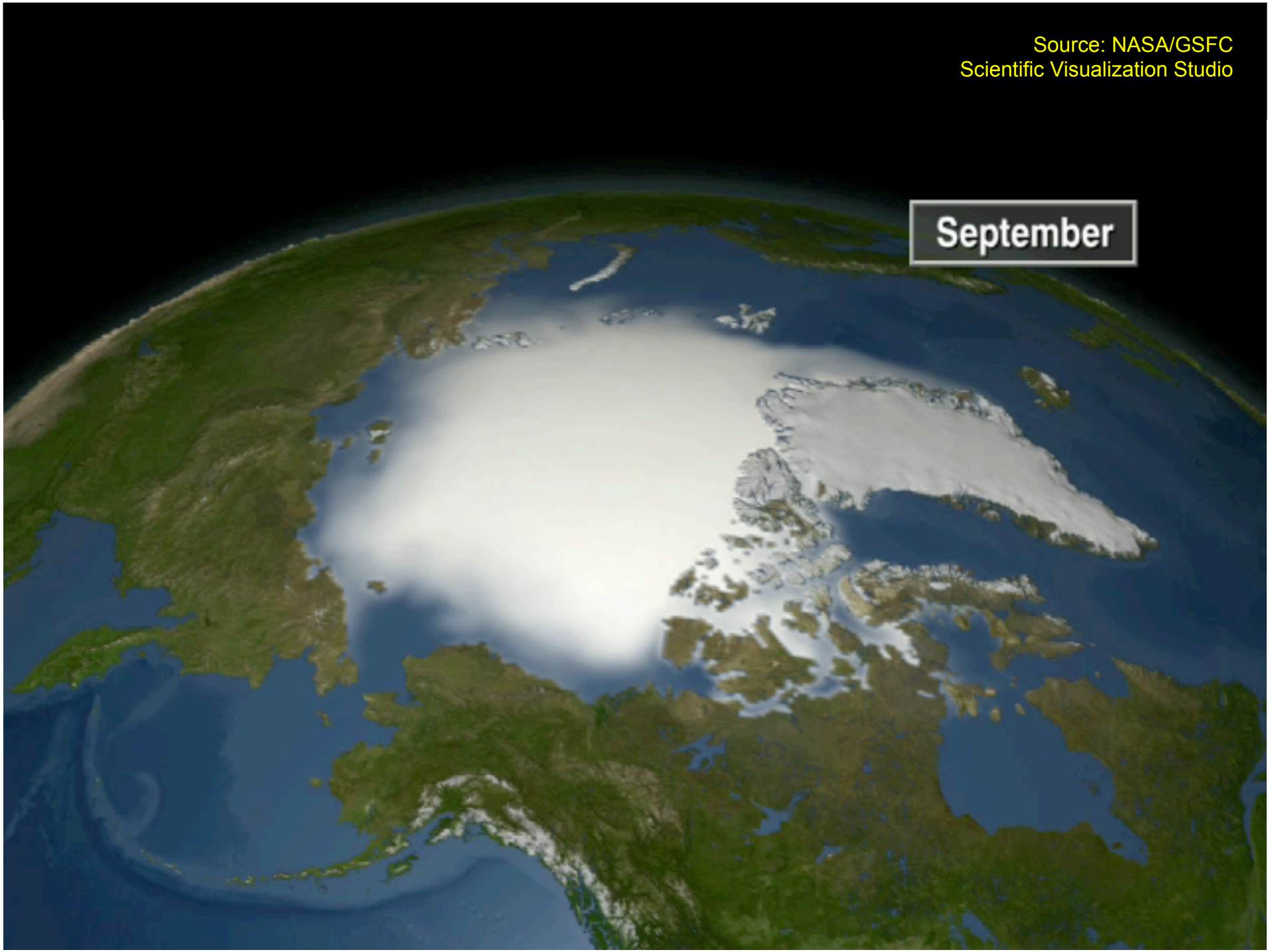
Sea Ice


Critical Tools for Understanding Sea Ice
Extent: Passive microwave, & Scatterometry
Thickness: Altimetry
Deformation: Synthetic Aperture Radar
Motion: Passive microwave & scatterometry
Concentration: Passive microwave
Reflectance: Visible Imagery
Temperature: Thermal IR

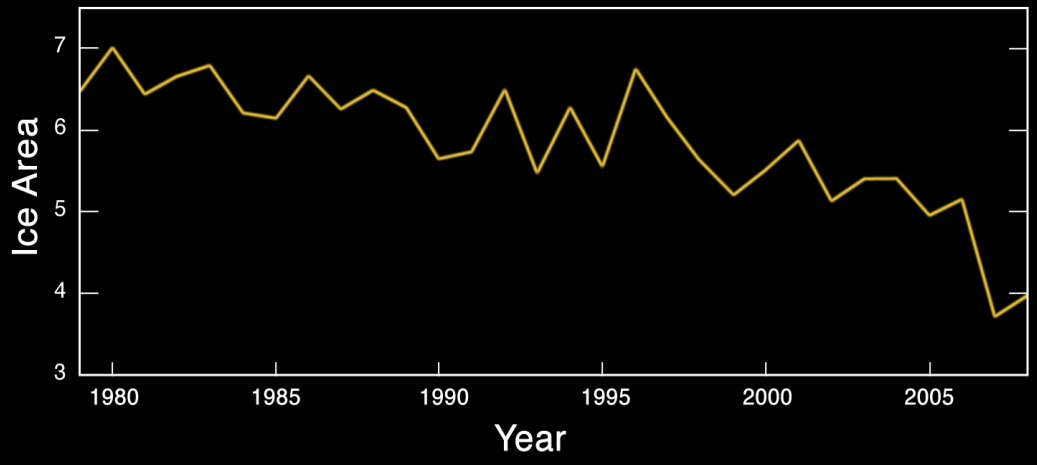
A Surprise in the Weddell Sea

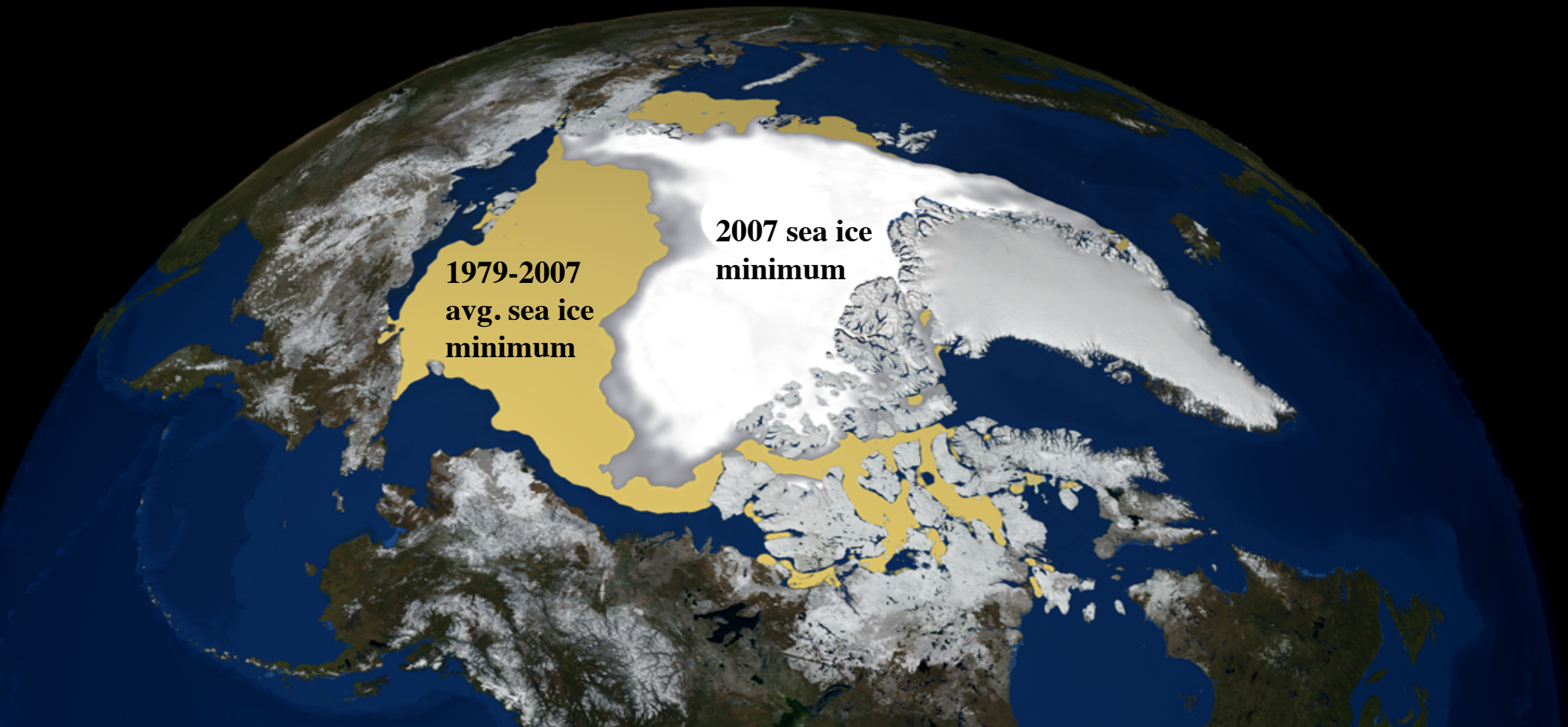


Source: Joey Comiso, NASA GSFC

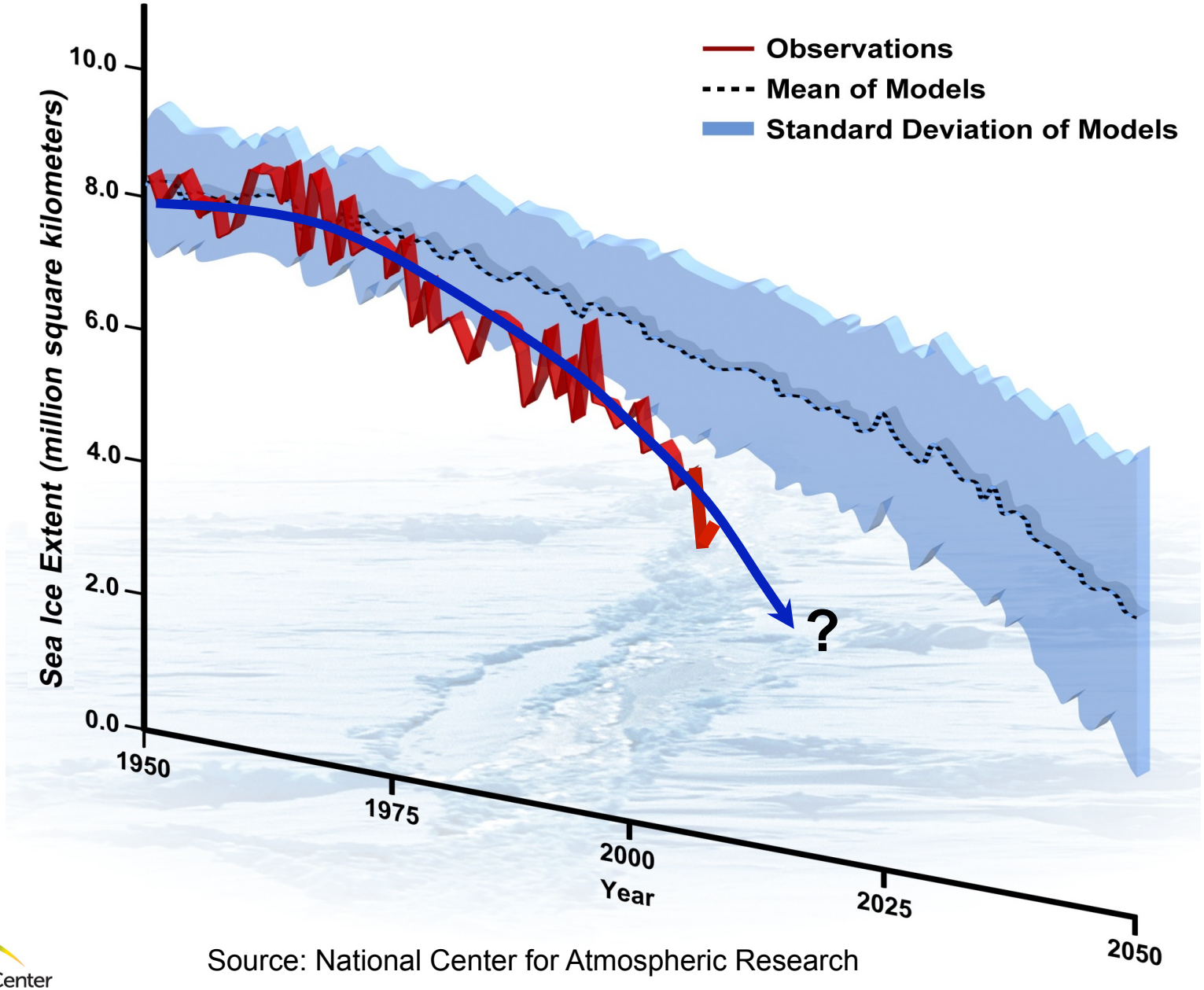

Source: NASA/GSFC
Scientific Visualization Studio
September

Annual Sea Ice Minimum Extent 1979-2008





Disappearing Arctic Sea Ice



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Source: National Center for Atmospheric Research

A Major Challenge: Ice Thickness

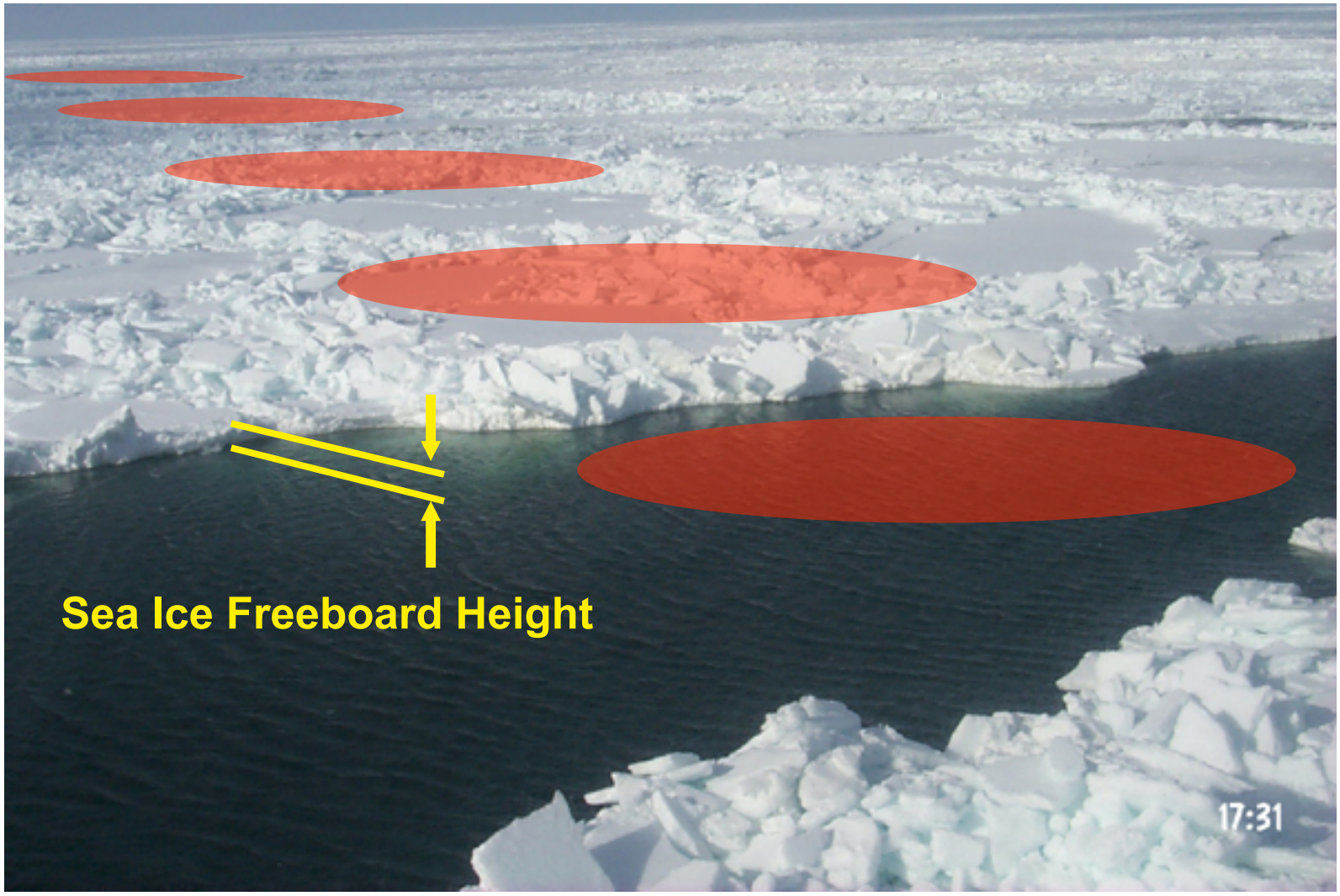

Photo source: Fisheries and Oceans Canada

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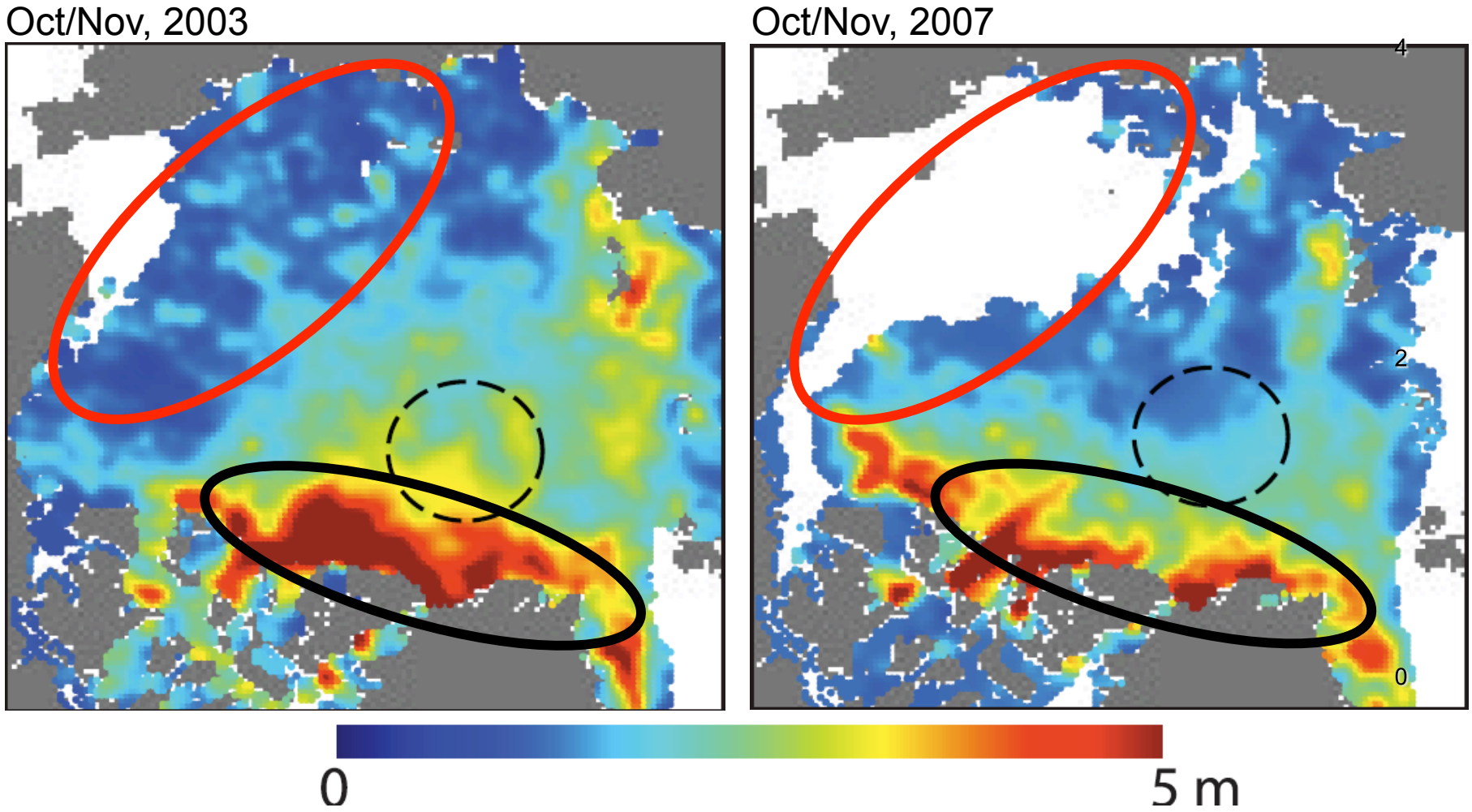
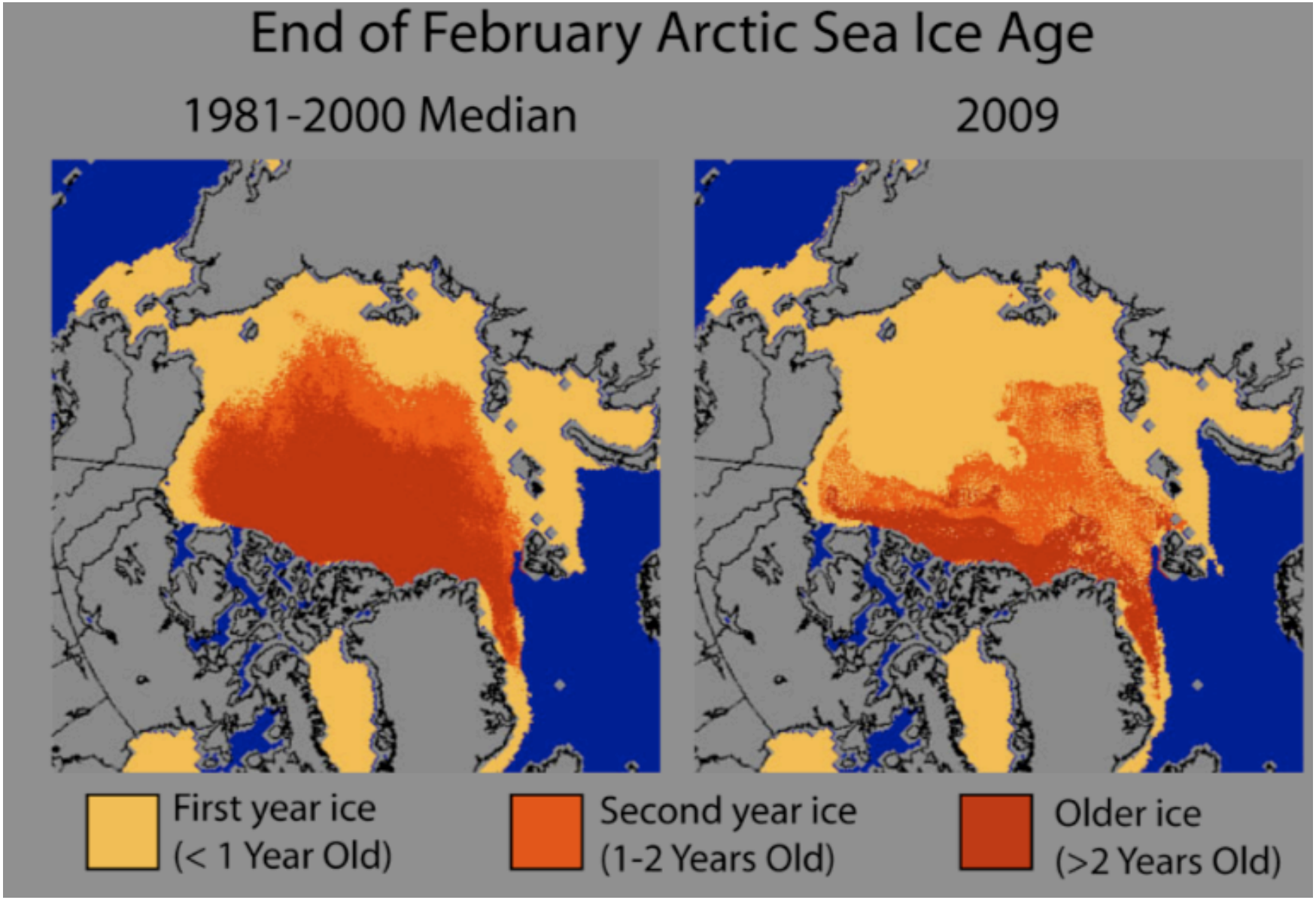
Thinning of Arctic Sea Ice



- 1-to-2 m thick ice thinned to <1m between 2003 and 2007 (Red Ovals)
- Most thick 3-to-5 m ice near Greenland is gone (Black Ovals)

From Kwok et al.2009 JGR Oceans



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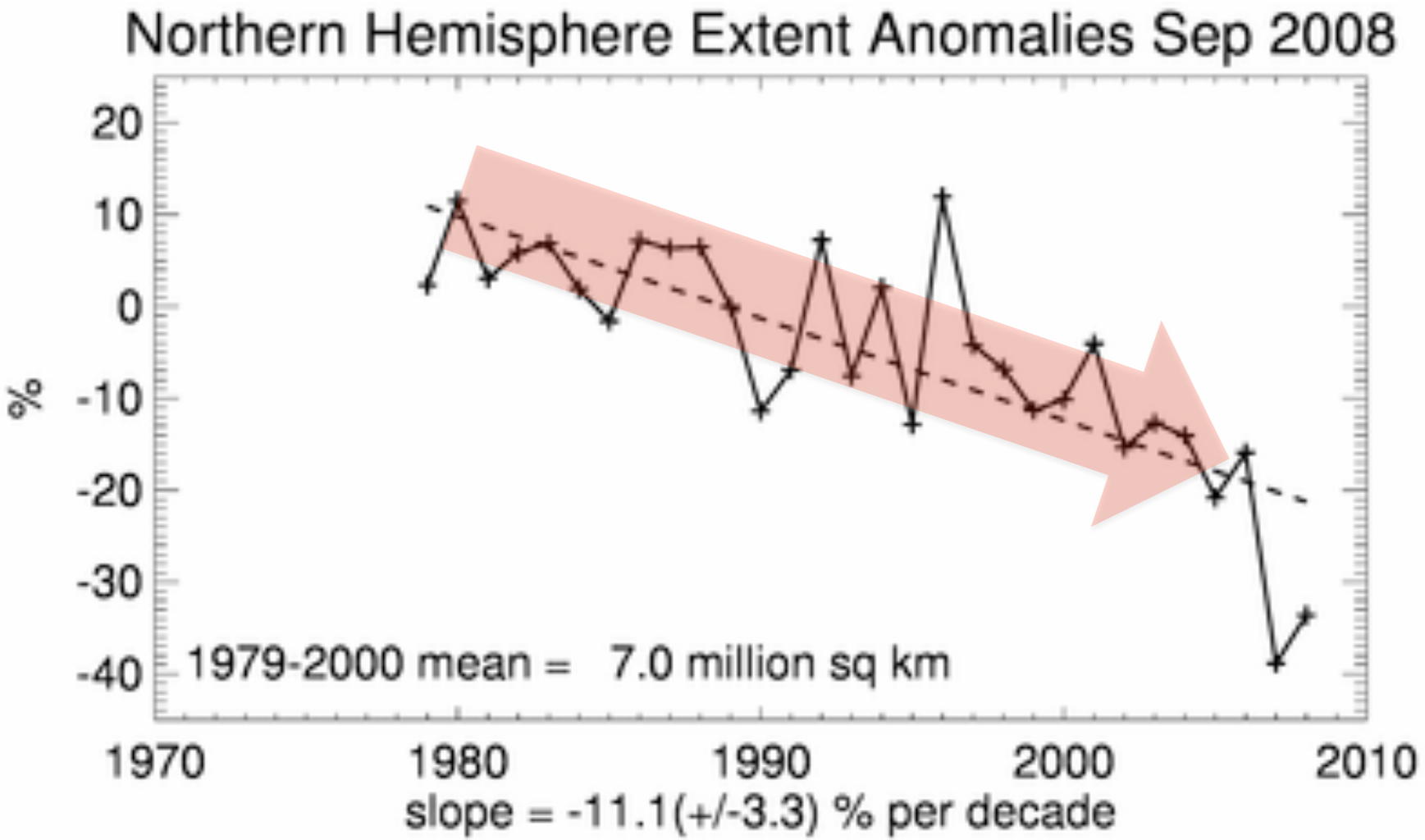
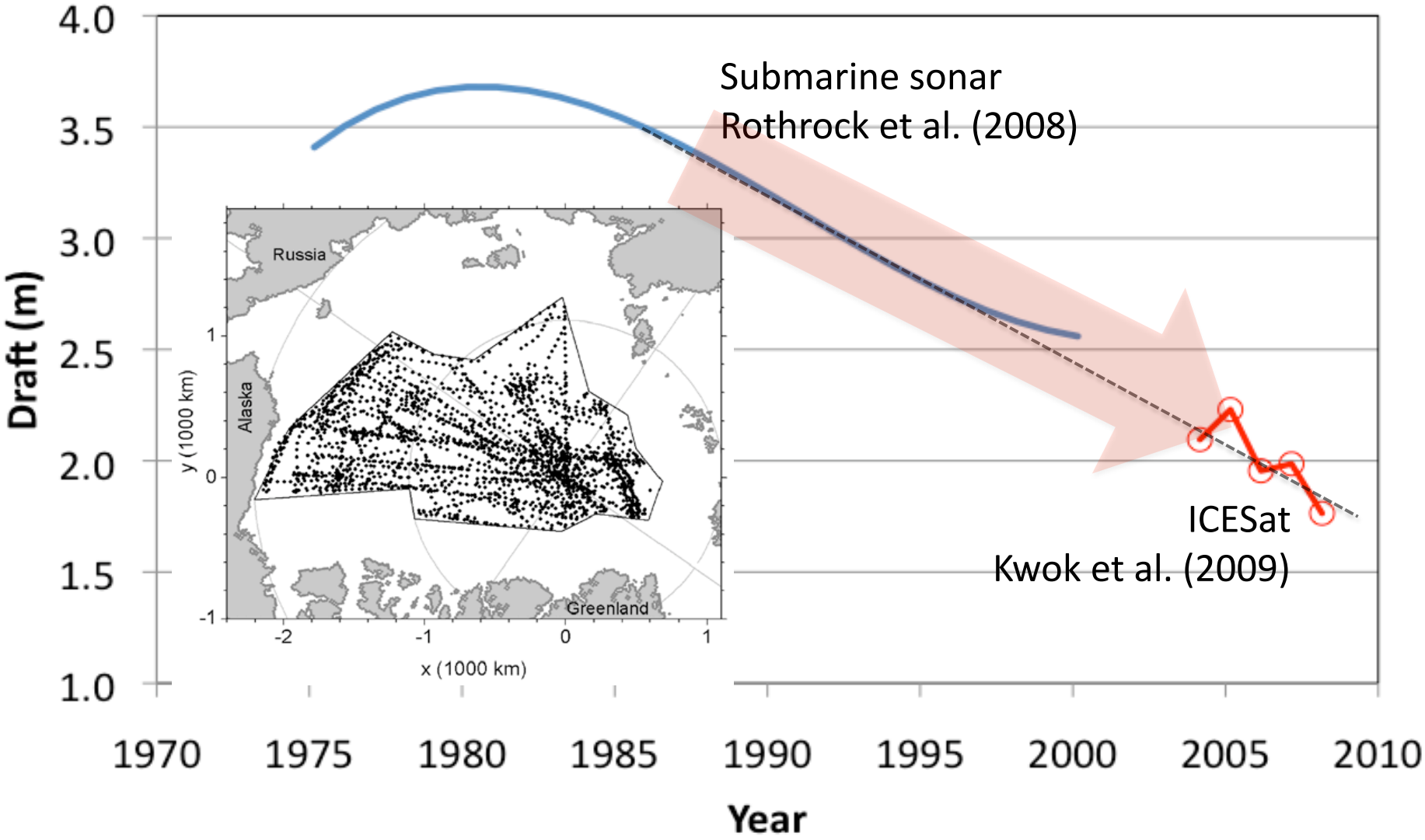
Source: National Snow and Ice Data Center
University of Colorado

Decrease in Arctic Sea Ice Area

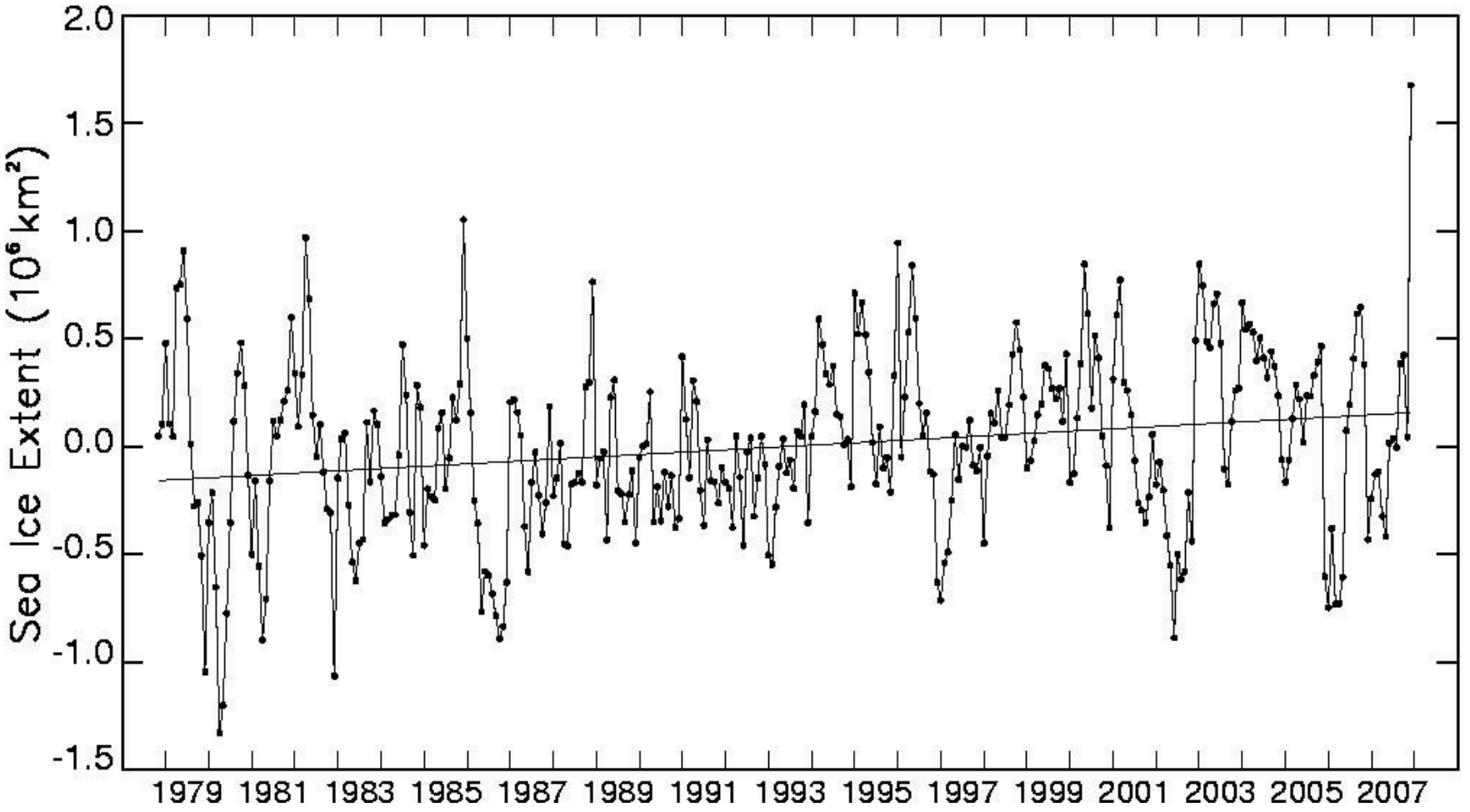


Decrease in Arctic Sea Ice Thickness

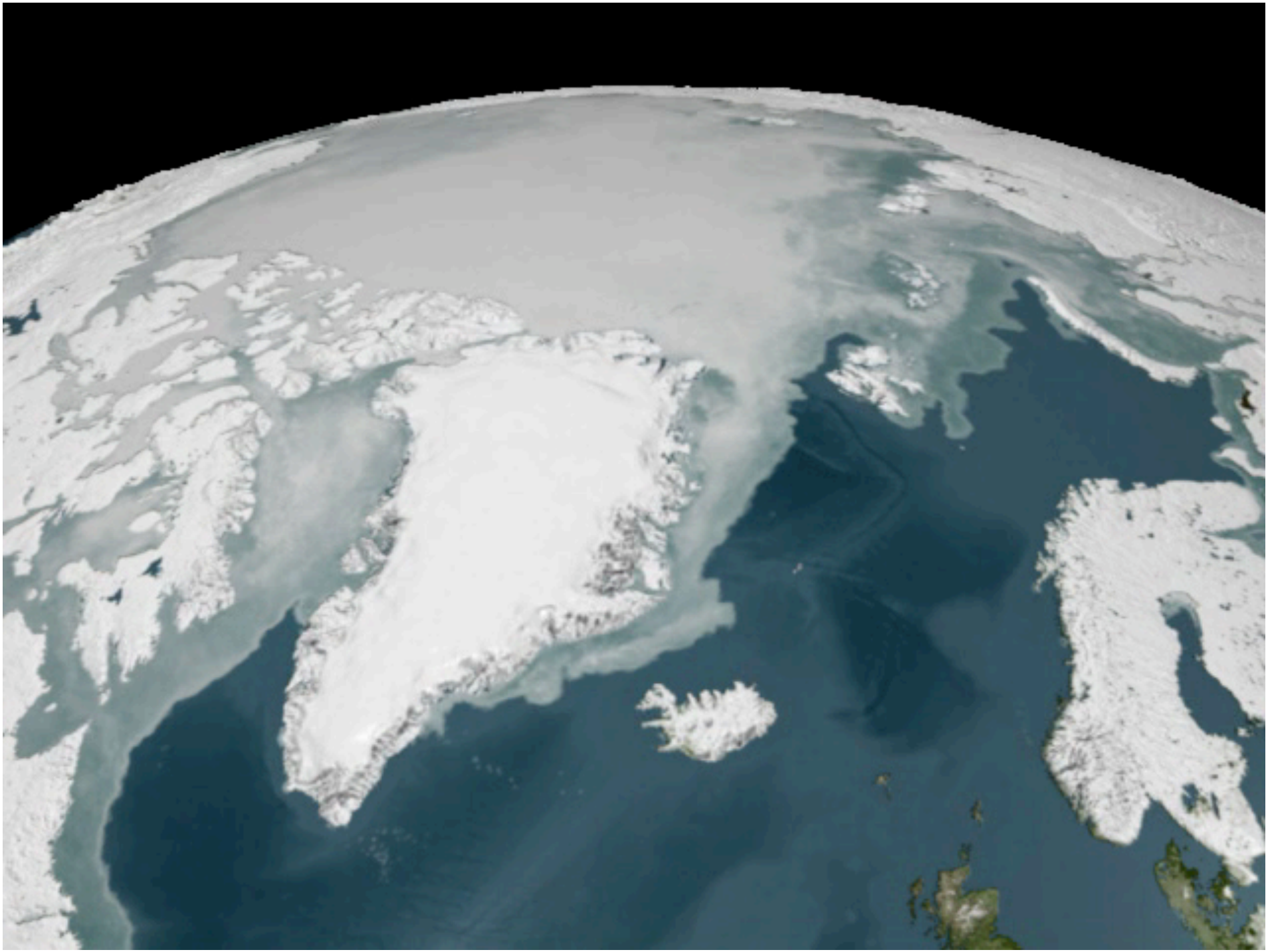


Source: Ron Kwok, JPL

Southern Hemisphere Sea Ice Is Increasing



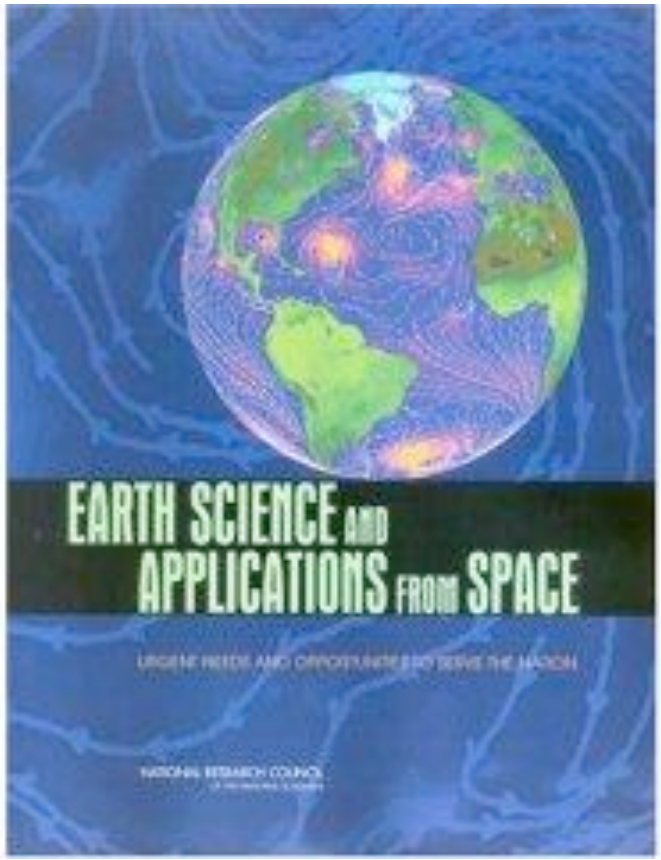
Source: Claire Parkinson NASA/GSFC



Other Recent Changes

- Amplified high latitude surface warming
  - Some Cooling in Antarctica
- Melting permafrost
- Earlier melt onset of Arctic sea ice
- Earlier lake- and river-ice break-up
- Earlier snow melt
- Ocean and atmospheric circulation changes

Future NASA Missions Focused on Ice



- Tier 1 (2010-2013)
  - ICESat-2
    - Laser altimetry
  - Deformation Ecosystem Structure and Dynamics of Ice (DESDynI)
    - InSAR and lidar combined system
- Tier 2 (2013-2016)
  - None
- Tier 3 (2016-2020)
  - Land Imaging Surface Topography
    - High rep-rate laser altimeter for land surfaces
  - GRACE-2

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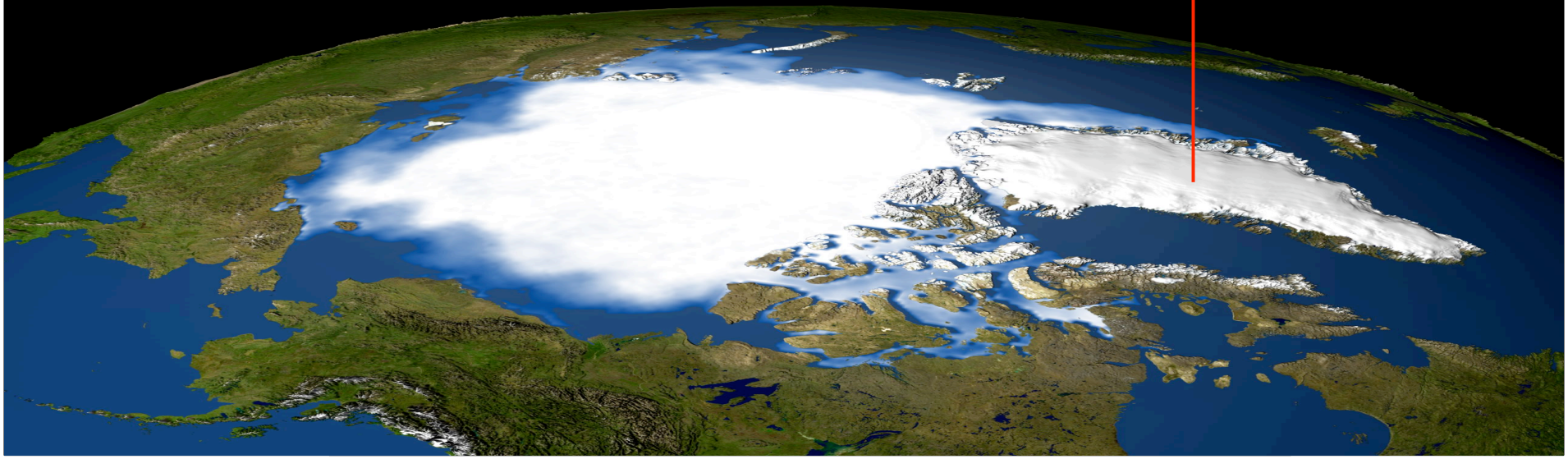
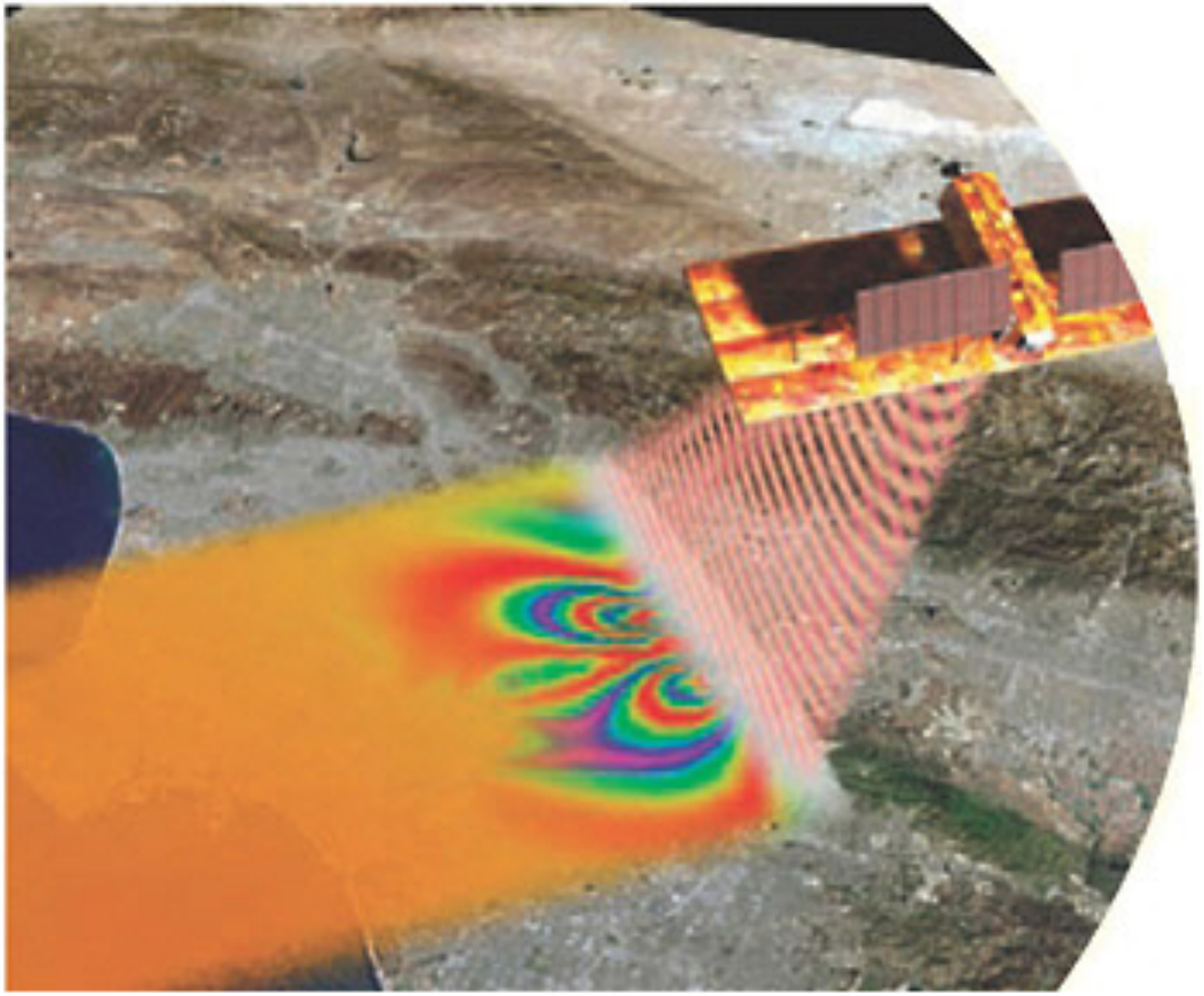
Ice Cloud and land Elevation Satellite-2
ICESat-2

- Laser Altimeter to measure changes in ice sheets and sea ice, and to map vegetation cover



Deformation Ecosystem Structure and Dynamics of Ice DESDynI



- L-Band Interferometric Synthetic Aperture Radar to measure Earth deformation, ice motion, and ecosystem structure
- Laser altimetry system to measure ecosystem structure

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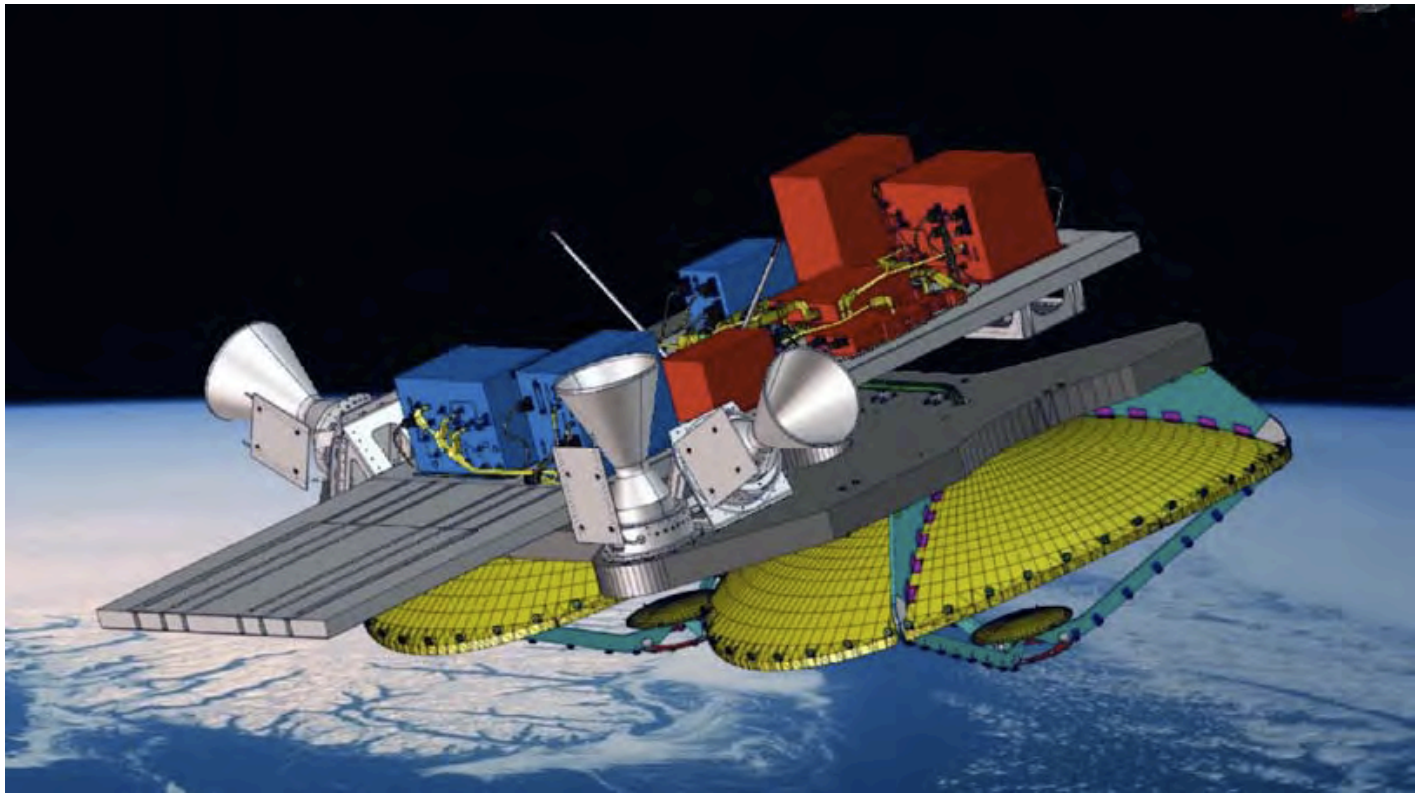
Cryosat-2



- Radar altimeter capable of high-resolution along-track measurements

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Other Relevant Missions/Instruments

- Operation IceBridge: Airborne surveys of ice sheets and sea ice
- GRACE-2: Third Tier, should be sooner
- LIST: Third Tier, and probably later than we think
- Passive Microwave
- Visible imagers
- Hyperspectral
- International
- Etc

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Changing the Way We Think

- Nearly instantaneous response of ice sheets to present-day forcings
- Dramatic acceleration of some of the fastest outlet glaciers in response to retreating ice
- Both Antarctica and Greenland are expected to lose mass in a warmer climate
- Summertime acceleration of large sections of Greenland in response to meltwater lubrication
- Rapid melting beneath floating ice tongues near grounding lines
- Active subglacial hydrologic network
- Increased melting of the Greenland ice sheet
- Detailed Mapping of entire Antarctic ice sheet

Changing the Way We Think

- Rapid collapses of large, thick, and old ice shelves
- Enhanced Arctic Warming
- Cooling over large parts of Antarctica in the last 20 years
- Formation and behavior of large scale Polynya in the Weddell Sea
- Decline of Arctic sea ice area, especially in summer
  - Significantly exceeds model predictions
- Increasingly younger and thinner ice cover in the Arctic
- Spatial character of Arctic sea ice thickness decline
- Increase in Antarctic ice area/extent


Climatologically we are in unfamiliar territory, and the world's ice cover is responding dramatically

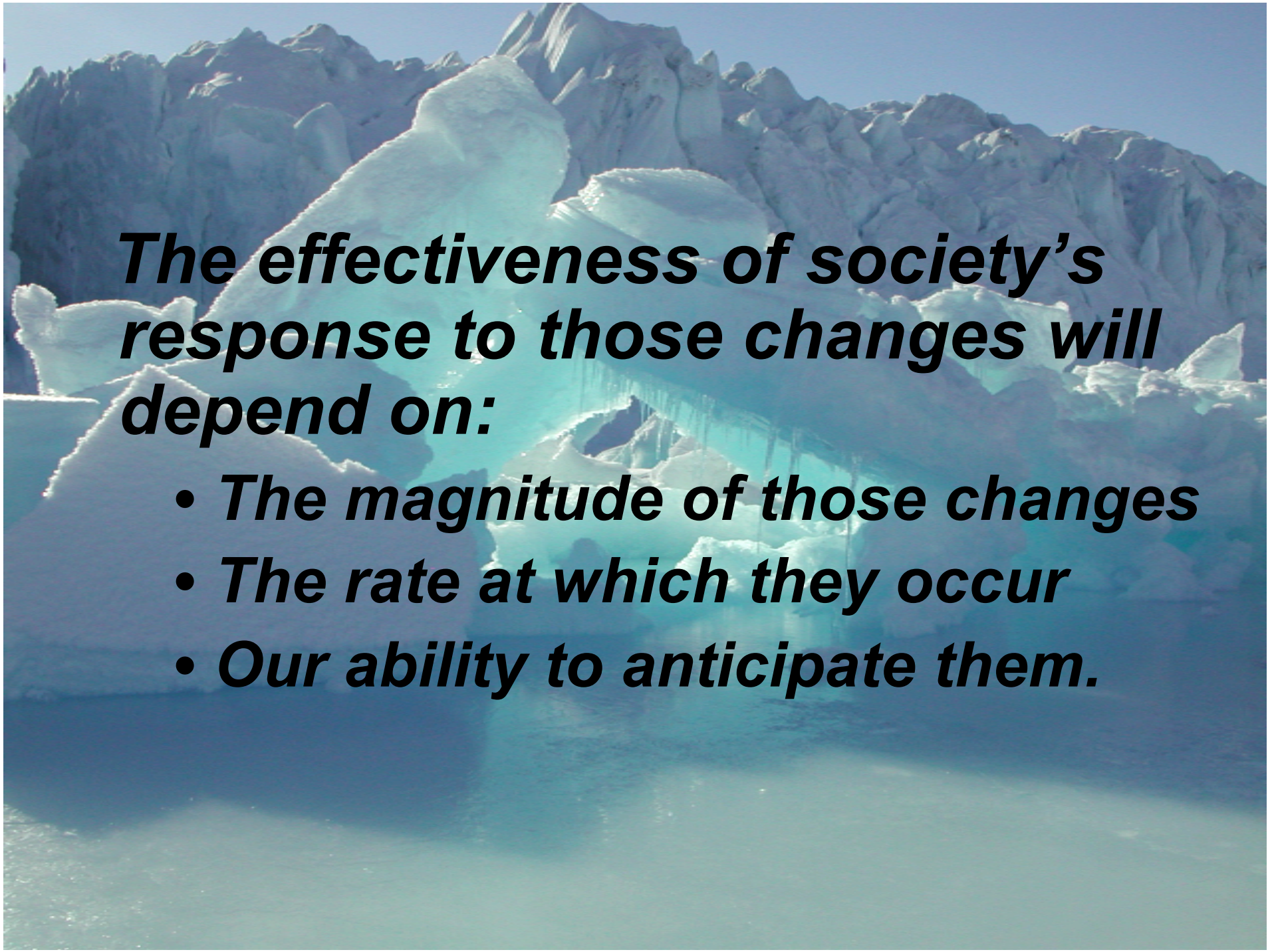
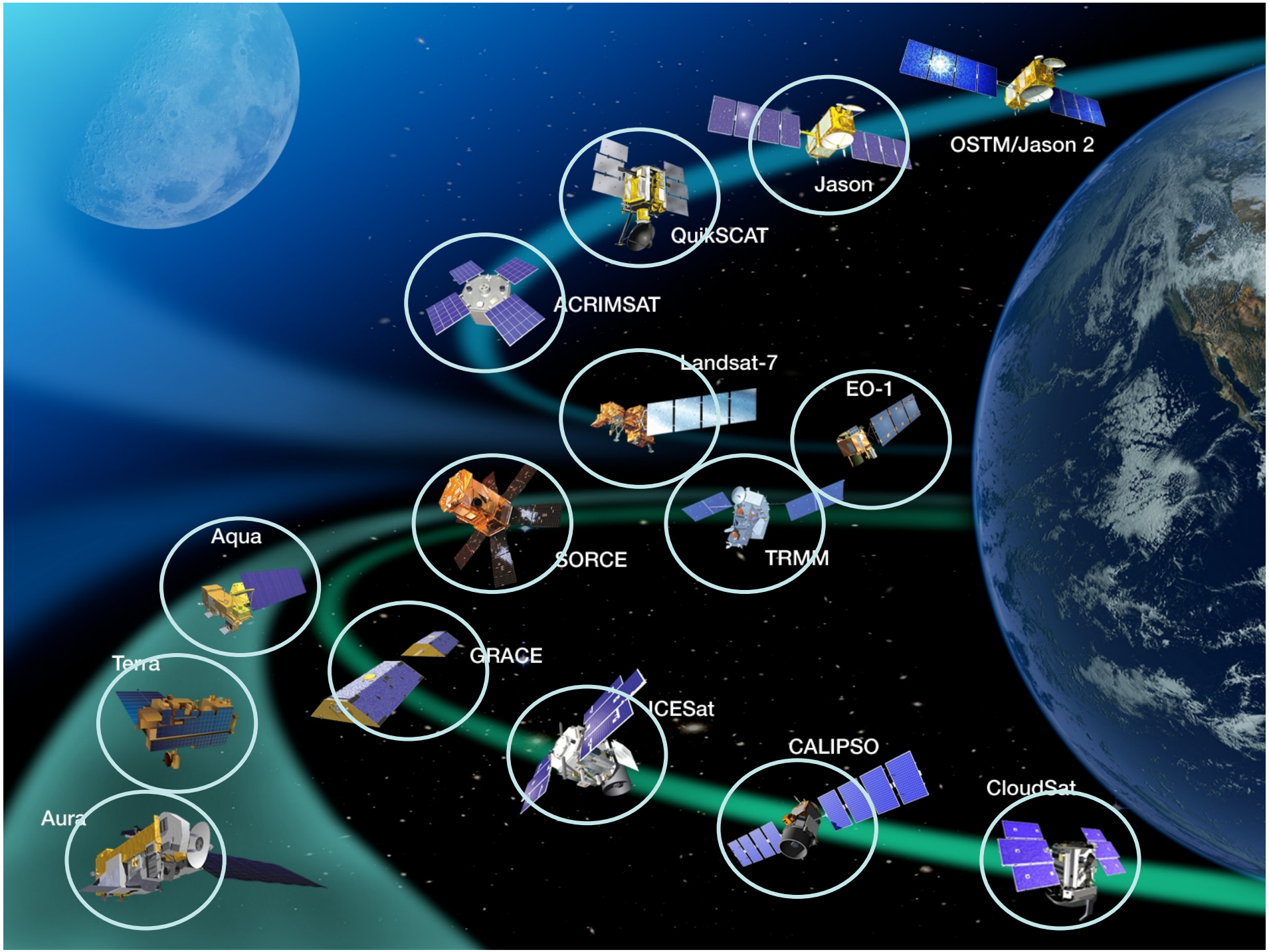
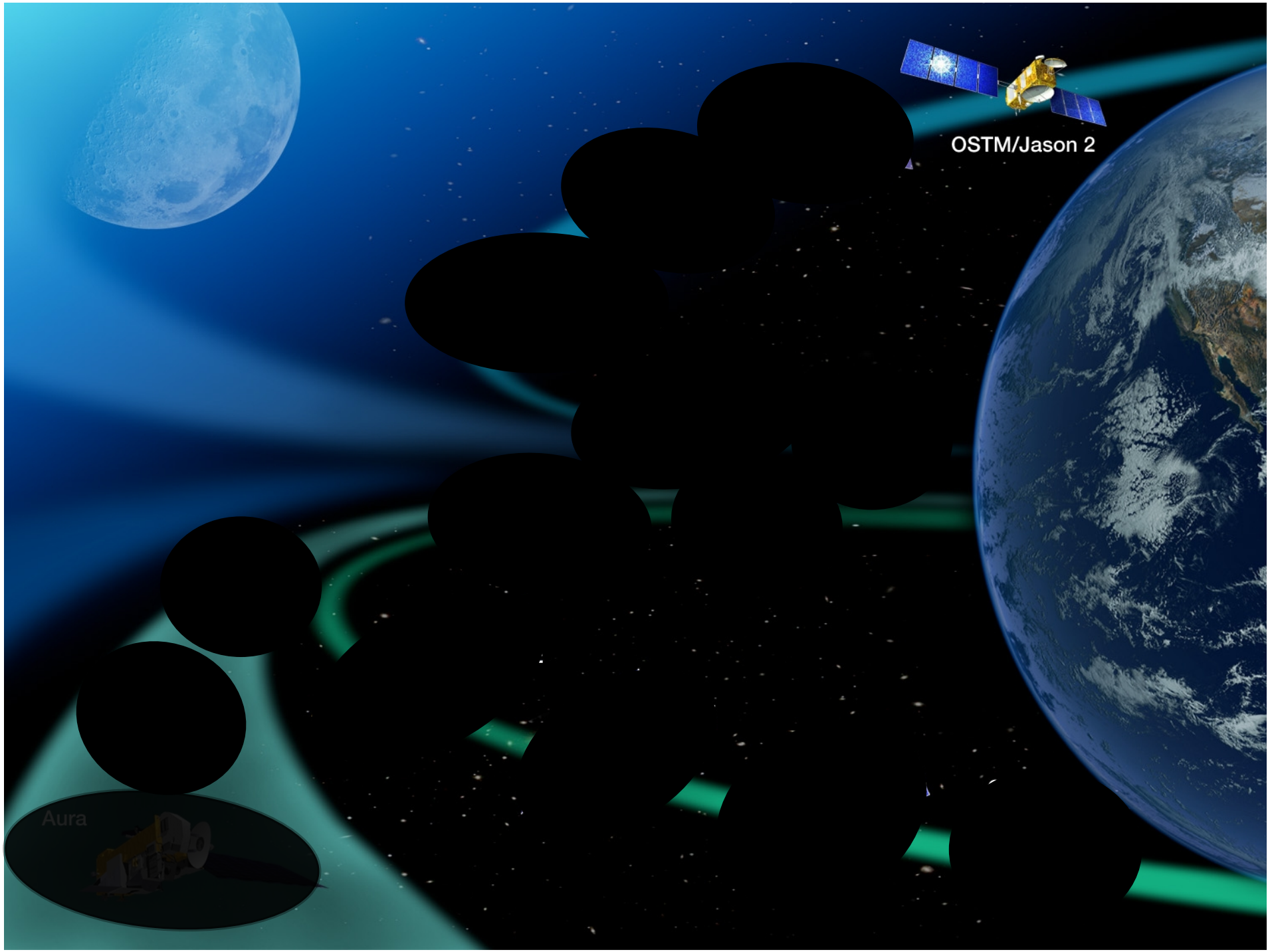

The effectiveness of society's response to those changes will depend on:
• The magnitude of those changes
• The rate at which they occur
• Our ability to anticipate them.

Photo by Ian Joughin, Univ. of Washington


OSTM/Jason 2
Jason
QuikSCAT
ACRIMSAT
Landsat-7
EO-1
SORCE
TRMM
Aqua
GRACE
Terra
ICESat
CALIPSO
CloudSat
Aura


OSTM/Jason 2
Aura

“Man must rise above the Earth - to the top of the atmosphere and beyond - for only thus will he fully understand the world in which he lives.”

Socrates